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Linking foodscapes and dietary behaviours: conceptual insights and empirical explorations in Canadian urban areas

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Linking foodscapes and dietary behaviours: conceptual insights and empirical explorations in Canadian urban areas

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Résumé

La manière dont notre environnement influence le lieu et la nature de nos achats alimentaires n'est pas bien comprise. Un accès facilité ou limité aux commerces d'alimentation dits « sains » et « non-sains » a été considéré comme central dans la relation entre environnement et comportements alimentaires. De fait, la recherche a surtout tenté d'établir un lien entre, d'une part, facilité d'accès aux commerces « sains » et comportement sains, et, d'autre part, « déserts alimentaires » – ces environnements socialement défavorisés offrant un accès limité aux sources d'alimentation saine – et comportements non sains. Les écrits en santé publique manquent cependant de perspective sur les facteurs influençant le lieu et la nature des achats alimentaires dans les situations où les options qui s'offrent aux individus sont multiples, saines et moins saines. Pourtant, dans les villes occidentales caractérisées par une densité de commerces élevée et une mobilité individuelle facilitée, la réunion des conditions d'accès aux commerces d'alimentation « sains » comme moins « sains » est probablement situation courante.

Partant de ce constat, cette thèse explore le lien entre environnements et comportements alimentaires dans plusieurs grandes villes canadiennes. En premier lieu, un cadre conceptuel est proposé, qui décrit les multiples facteurs influençant le lieu et la nature des achats alimentaires. Partant du postulat couramment adopté selon lequel les individus cherchent à tirer un maximum de bénéfices de leur environnement, ce cadre souligne l'importance de considérer les caractéristiques des commerces d'alimentation « sains » et « non sains » (ex. localisation, prix) en relation avec les préférences, moyens et contraintes des individus. L'attention est cependant attirée sur la capacité limitée des individus à opérer des choix pleinement informés. En effet, la réalisation de ces choix s'opère parfois sans grande conscience, en réaction à certains stimuli environnementaux. Sont notamment discutées les situations dans lesquelles le caractère approprié d'un comportement alimentaire est implicitement suggéré par l'environnement. Il est proposé que les densités relatives de commerces alimentaires « sains » et « non-sains » dans l'environnement auquel les individus sont exposés refléteraient la relative popularité de ces lieux d'achat, et suggèreraient quels types de commerce il est « approprié » d'utiliser.

Pour tester la plausibilité d'une telle proposition, cette thèse explore dans quelle mesure le pourcentage de commerces « sains » dans l'environnement des résidents adultes de cinq grands pôles urbains au Canada est associé à leur consommation de fruits et légumes. Les recherches présentées dans cette thèse portent à la fois sur les environnements autour du lieu de résidence (environnement résidentiel) et autour des divers lieux fréquentés par ces individus (environnement non résidentiel). Sont également testées d'éventuelles différences homme-femme dans ces associations, des différences de genre ayant été soulignées dans les recherches s'intéressant à la relation entre environnements et comportements alimentaires.

Conformément aux hypothèses émises, une association positive entre pourcentage de magasins « sains » dans l'environnement résidentiel et consommation de fruits et légumes est observée. Une relation plus forte chez les hommes que chez les femmes est également relevée. En revanche, la consommation de fruits et légumes n'est pas reliée au pourcentage de magasins « sains » dans l'environnement non résidentiel et ce, ni chez les hommes ni chez les femmes.

En proposant un cadre conceptuel innovant, que viennent en partie conforter les résultats de notre recherche empirique, cette thèse contribue à la construction d'une meilleure compréhension des influences environnementales sur les comportements de santé.

Mots-clés: environnement alimentaire; accès; exposition; environnements résidentiel et non résidentiel; comportements alimentaires; fruits et légumes; différences de genre; adultes; Canada.

Summary

In westernised cities where food is mostly acquired in the retail and catering environment, there may be a link between the *foodscape* - i.e. the multiplicity of publicly available sites where food is displayed for purchase - and where and what we buy and eat. Yet, how the foodscape shapes dietary behaviours remains unclear. Ease and difficulty of access to "healthy" and "unhealthy" food sources has been recognised as central in the foodscape-diet relationship. As a result, empirical research has mostly investigated the associations between ease of access to healthy outlets and healthy behaviours, on one hand, and "food deserts" – deprived environments lacking access to healthy food outlets – and unhealthy behaviours, on the other hand. However, public health literature lacks perspective on the factors that influence where to purchase and what to eat in situations of multiple – healthy and less healthy – choices. Yet, in industrialised urban contexts characterised by pervasive food retail and facilitated individual mobility, conditions for accessing both healthy and less-healthy food sources are probably commonly met.

Based on these observations, this thesis intents to explore the relationship between foodscapes and dietary behaviours in Canadian urban areas. Firstly, conceptual insights on the multiple factors shaping where to shop and what to eat are provided. Drawing from the commonly held assumption that individuals operate choices that tend to maximize their self-interests, the proposal highlights the importance of considering food outlets' characteristics (ex. localisation, price, services offered) relatively to individuals' preferences, constraints and means. However attention is brought on individuals' limited ability to operate fully-informed choices. Food choices sometimes unfold without much deliberation, as a result of the mere perception of cues in the environment. Especially discussed are the situations where exposure to cues signaling appropriateness of a dietary behaviour provokes the adoption of similar behaviours. It is then suggested that the relative densities of healthy and unhealthy outlets individuals get exposed to may drive a normative message about the relative popularity of these places, and suggest which places are “appropriate” to use.

This thesis then investigates the extent to which relative exposures to healthy and unhealthy food outlets are associated to dietary behaviours. Drawing on multiple secondary datasets pertaining to adult residents of five large Canadian cities, associations between the percentage of healthy outlets in the residential neighborhood and fruit and vegetables intake are examined. As literature highlighted gender differences in the foodscape-diet relationship, whether these associations are different for men and women are further investigated. Finally, these investigations extend to the non-residential environment.

Consistent with our expectations, our research provides evidence of a positive association between the percentage of healthy outlets around home and fruit and vegetable intake. Stronger associations for men than for women were further observed. However, fruit and vegetable intake was not related to the non-residential foodscape, neither for men nor for women.

By providing conceptual justification for, and empirical evidence of, a link between dietary behaviours and relative exposures to healthy and unhealthy outlets, this thesis contributes to better understand how the foodscape shapes dietary behaviours.

Keywords: foodscape; access; relative exposure; residential and non-residential environments; dietary behaviors; fruit and vegetable; gender-differences; adults; Canada.

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List of abbreviations

AIC	Aikake Information Criteria
CCHS	Canadian Community Health Survey
CMAs	Census Metropolitan Areas
CT	census tract
DA	dissemination area
EPOI	Enhanced Points of Interest
FFQ	food frequency questionnaire
FFR	fast-food restaurants
FSR	full-service restaurants
FVI	fruit and vegetable intakes
FVS	fruit and vegetable stores
GIS	Geographic Information Systems
GWR	geographically weighted regressions
KDE	Kernel Density Estimation
MCMA	Montreal Census Metropolitan Area
MI	Multiple Imputation
NFS	natural food stores
OD	Origin-Destination
RFEI	Retail Food Environment Index
SIC	Standard Industrial Classification
VIF	Variance Inflation Factor

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CHAPTER 1. INTRODUCTION

1.1. From food deprivation to food abundance, the sustaining burden of diet-related diseases

For millennia, the human race struggled to overcome hostile environments, food scarcity and undernutrition-related diseases. From the earliest forms of agriculture to the advent of the industrial revolution, humans have continuously sought to push aside the limits of food insecurity (Weill 2007). Well-fed individuals are necessary to healthy populations and, in turn, social equilibrium, a good economy and the political might of nations. Accordingly, countries have intended to increase food availability for their growing populations by supporting the development of efficient food systems based on intensive farming practices, mechanical and computerized food-processing (Cotterill 1992; Caballero 2007), novel foods (Cordain, Eaton et al. 2005) and large-scale retailing (Wrigley and Lowe 1998). Partly as a result of these efforts, westernised countries have progressively seen the height, weight and life expectancy of their population increase (Caballero 2007). Yet from the 1950s onwards and the raging epidemic of diet-related chronic diseases across industrialised countries (WHO/FAO 2003), the challenge of feeding people became of a different nature for governments (Caraher and Coveney 2004).

From the mid-20th century, epidemiological studies have pointed out the existence of a link between the nutritional quality of diet and a set of increasingly prevalent chronic diseases (Dawber, Meadors et al. 1951; Keys, Menotti et al. 1986), including type 2 diabetes (van Dam, Rimm et al. 2002; Hu 2011), cardiovascular diseases (Fung, Willett et al. 2001; Mente, de Koning et al. 2009; Lee, Kim et al. 2011), and certain cancers (Hill 1987; Block, Patterson et al. 1992; Slattery, Boucher et al. 1998). For instance, abundant research agreed on the health-detrimental effect of high intakes of sugar (Malik, Popkin et al. 2010; Malik, Pan et al. 2013; Yang, Zhang et al. 2014) and saturated fat (Hu, Manson et al. 2001; Mozaffarian, Katan et al. 2006). Inversely, the protective effect on health of certain foods like fruit and vegetable was widely recognised (Ness and Powles 1997; Liu, Manson et al. 2000; Lock, Pomerleau et al. 2005; Pomerleau, Lock et al. 2006; Wang, Ouyang et al. 2014). Hence, it has been acknowledged that it is not just the overall quantity of foods consumed by populations that matters, but also the nutritional quality of these foods.

The enormous costs of nutrition-related diseases for governments, and their dramatic consequences on people's life (Gortmaker, Must et al. 1993; Wellman and Friedberg 2002), have pushed health authorities to adopt preventive measures (Tunstall-Pedoe 2006). The political individualism dominant from the 1950s onwards in many industrialised countries, added with methodological and conceptual emphasis on risk factors in epidemiological studies, encouraged countries to adopt behavioural change perspectives among at-risk individuals (Macintyre, Ellaway et al. 2002). Health authorities came up with nutritional guidelines providing recommendations on the target amount or frequency of consumption of foods deemed to play a key role in a balanced diet (Nishida, Uauy et al. 2004). Educational programs were implemented (Sherwin, Kaelber et al. 1981; Farquhar, Fortmann et al. 1985; WHO 1997; Antipatis, Kumanyika et al. 1999) with intent to shift unhealthy diets towards diets more consistent with these national guidelines. Yet, the spread of chronic diseases kept occurring in the face of increasing education about nutrition (Foreyt, Goodrick et al. 1981; Carleton, Lasater et al. 1995; Orleans 2000).

1.2. Toward the increasing recognition of environmental influences on dietary behaviours

1.2.1. Advent of ecological models

Nurtured by the observation of social (Steele, Dobson et al. 1991; Roos, Lahelma et al. 1998; Martikainen, Brunner et al. 2003) and spatial (Daniel, Kestens et al. 2009; Lebel, Pampalon et al. 2009; Michimi and Wimberly 2010) patterning of dietary behaviours, the late 1990s have seen research interest redirected towards environmental effects on health behaviours (Macintyre, Ellaway et al. 2002; Entwisle 2007). With the advent of ecological models for health promotion over that same period (Sallis, Owen et al. 2008; Richard, Gauvin et al. 2011), physical and social environments became increasingly recognised as potent determinants of what we eat (Booth, Sallis et al. 2001; Glanz, Sallis et al. 2005). A central tenet of ecological models is that it usually takes the combination of both individual and environmental factors to explain health behaviours (Sallis, Owen et al. 2008). For instance, individuals with strong health awareness may be limited in their intent to consume fruit and vegetables if their environment does not readily provide such foods. Inversely, living in an environment providing plentiful fruit and vegetables does no guarantee that people will make use of that resource. In short, healthy behaviours are thought to be maximized when environments support healthy choices, and individuals are motivated to make those choices (WHO 1986; Wang, MacLeod et al. 2007). Alongside keeping on educating people, the public health nutrition field has therefore sought to identify the health-promoting and health-detrimental features of the food environment (Holsten 2009; Giskes, van Lenthe et al. 2011).

1.2.2. Geographies of food retail and dietary behaviours: synchronised evolutions

In the westernised world where food is mostly acquired through market-guided systems (Eckert and Shetty 2011), attention has been especially directed towards the retailing and catering environment, or *foodscape*, defined as the multiplicity of publicly available sites where food is displayed for purchase (Winson 2004). The 1950s onwards have witnessed considerable changes in the foodscape across most industrialised countries, especially in North America. The emergence of large chain-owned supermarkets on the edge of towns (Cotterill 1992; Wrigley 1998; Guy, Clarke et al. 2004; Einarsson 2008) and more recently their inner-city reduced-scale variant (Jeffery, Baxter et al. 2006; White 2007; Cohen 2008; Black, Moon et al. 2014), has resulted in a decline in the number of smaller general and specialist grocery shops (Wilson and Oulton 1983; Fotheringham and Knudsen 1986; Cotterill 1992; Guy 1996; Wrigley 1998; Guy, Clarke et al. 2004; White 2007). Chaining allowed retailers to lower operating costs, while offering a great selection of goods, undermining the attractiveness of local grocers (Wrigley and Lowe 1998). In parallel, cities have witnessed the rapid multiplication of fast-food restaurants and convenience stores (Cotterill 1992; Wrigley 1998; Guy, Clarke et al. 2004).

Overall, this evolution led to an increased availability of food at the city scale. Yet, from a public health nutrition perspective, this should be considered with a more nuanced view. Food outlets are not similar in quality from a health standpoint. Studies have pointed out in-store disparities in the availability of both healthy and unhealthy foods. Overall, supermarkets, fruit and vegetable stores and grocery stores propose a wider range of food items whose consumption is advocated by health authorities (e.g. fruit and vegetables) than convenience stores and fast-food restaurants (Lewis, Sloane et al. 2005; Rose, Bodor et al. 2009; Reedy, Krebs-Smith et al. 2010; Ohri-Vachaspati, Martinez et al. 2011; Black, Ntani et al. 2014). They also have a greater ratio of the total shelf space dedicated to healthy food items to the total shelf space dedicated to unhealthy items (Farley, Rice et al. 2009; Zenk, Powell et al. 2014). Now, there is some evidence that the higher the availability of healthy foods in stores, the higher the quality of customers' diet (Cheadle, Psaty et al. 1991; Fisher and Strogatz 1999; Zenk, Schulz et al. 2005; D'Angelo, Suratkar et al. 2011; Aggarwal, Cook et al. 2014). This makes sense in the light of marketing research on shelf space demonstrating that supply can drive demand (Curhan 1973; Curhan 1974; Chevalier 1975; Wilkinson, Mason et al. 1982; Desmet and Renaudin 1998; Eisend 2014). Drawing on the assumption that food outlet type influences food choice, supermarkets (chain and independent), grocery stores and fruit and vegetable stores/markets have been traditionally referred to as "healthy" resources, while convenience stores and fast-food restaurants as "unhealthy" ones (Sallis, Nader et al. 1986; Horowitz, Colson et al. 2004; Ohri-Vachaspati, Martinez et al. 2011; Cannuscio, Tappe et al. 2013; Black, Ntani et al. 2014).

From a public health perspective, this retail evolution has hence been marked by two trends: on one hand, the transition from small-scale and dispersed to large-scale and clustered healthy food sources, and on the other hand, the local invasion of unhealthy food stores. Recent research has consistently reported an overwhelming predominance in the number of unhealthy outlets compared to healthy ones. For instance, there are almost 12.5 times more fast-food outlets than supermarkets in Edmonton (Smoyer-Tomic, Spence et al. 2008). Cannuscio et al. have reported that convenience stores comprise almost 80% of the food retail outlets in the 30 Philadelphia city blocks they have studied (Cannuscio, Hillier et al. 2014). The average California adult is exposed to four times as many fast-food restaurant and convenience stores than supermarkets, grocery stores and markets (Babey, Diamant et al. 2008). Consistently, the residential neighbourhood of adults living in one of the five largest Canadian cities encloses on average three times as many unhealthy outlets than healthy outlets (Clary, Ramos et al. 2014). In a similar vein, a study based in Cambridgeshire, UK, reported an overwhelming majority of convenience stores and takeaways/fast-food restaurants compared to supermarkets, both around home and work places of the participants (Burgoine and Monsivais 2013).

Locally, this evolution has resulted in disparities in the availability of food resources, with areas facing a disproportionate lack of healthy food resources or abundance of unhealthy ones. Depicted through the metaphor of "urban grocery store gaps" (Cotterill and Franklin 1995) these trends have been well-documented (Smoyer-Tomic, Spence et al. 2008), especially in the field of social justice interested in disparities with regard to neighbourhood-level SES. Overall, this literature has consistently referenced unequal distribution across urban neighbourhoods, both regarding supermarkets (Cotterill and Franklin 1995; Moore and Diez Roux 2006; Ford and Dzewaltowski 2008; Larson, Story et al. 2009; Lovasi, Hutson et al. 2009; Rose, Bodor et al. 2009; Walker, Keane et al. 2010) - chain and non-chain (Powell, Slater et al. 2007), grocery stores (Moore and Diez Roux 2006; Powell, Slater et al. 2007; Beaulac, Kristjansson et al. 2009; Walker, Keane et al. 2010), convenience stores (Powell, Slater et al. 2007; Rose, Bodor et al. 2009), fast-food restaurants (Powell, Chaloupka et al. 2007; Smoyer-Tomic, Spence et al. 2008; Daniel, Kestens et al. 2009; Larson, Story et al. 2009; Lovasi, Hutson et al. 2009; Fraser, Edwards et al. 2010; Hilmers, Hilmers et al. 2012), but also fruit and vegetable stores, bakeries, specialty stores, and natural food stores (Moore and Diez Roux 2006).

Parallel to this food retail evolution, westernised countries have witnessed significant changes in dietary behaviours, both regarding the quality of the diet and the mode of consumption. There is consistent evidence of a shift towards more refined sugar (HCSP 2000; Popkin and Nielsen 2003; Cordain, Eaton et al. 2005; Garriguet 2007; Wells and Buzby 2008) – partly linked to increased soft drink intakes (Harnack, Stang et al. 1999; Popkin and Nielsen 2003; Nielsen and Popkin 2004), and fat (Chevassus-Agnès 1994; USDA 1998; HCSP 2000; Cordain, Eaton et al. 2005; Garriguet 2007; Wells and Buzby 2008). Concomitantly, an increase in away-from-home eating practices has been reported (Zizza, Siega-Riz et al. 2001; Popkin and Nielsen 2003; Garriguet 2007). Those changes have been particularly well documented in North America, but similar trends have been observed in Europe (Ziegler 1967; Cordain, Eaton et al. 2005; Hébel 2011).

The potential impact of this changing foodscape on local consumer's dietary behaviours has therefore been the focus of many studies.

1.3. Linking foodscape and dietary behaviours

1.3.1. The central concept of access

It has been largely accepted that the foodscape influences dietary behaviours by enabling or limiting the acquisition of healthy and unhealthy foods (Story, Kaphingst et al. 2008). Driven by the fundamental assumption that the effort to reach a food resource declines with decreasing distance from home, especially due to time and transportation cost (Pacione 1974; Brown 1989), research has mainly approached the question of access to food resources in terms of spatial accessibility (Charreire, Casey et al. 2010). Under that perspective, consumers have been assumed to patronize the nearest places from home that offer the required goods or services. The type(s) of food resources located in close vicinity from home have hence been presumed to shape dietary behaviours (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012; Black, Moon et al. 2014). In the context of disparities in the healthy and unhealthy food outlets distributions (described above), a considerable amount of research has assessed the extent to which shortened distance from home to, or increased density around home of healthy and unhealthy food sources would relate to dietary behaviours. Particularly prolific, research on 'food deserts' has focused on the situation where poor people live in residential areas lacking healthy food options (Cummins and Macintyre 2002).

Yet, discrepancies in findings (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012) have pushed researchers to question the conceptual positions they were relying on regarding how the foodscape relates to dietary behaviours (Cummins, Curtis et al. 2007; Lytle 2009). In recent years, conceptual refinements of *access* have been driven by two considerations. First, in an era of facilitated mobility (Miller 2007), individuals actually tend to purchase food outside their residential neighbourhood (Day 1973; Inagami, Cohen et al. 2006; Hillier, Cannuscio et al. 2011; Kerr, Frank et al. 2012). Thus, defining access exclusively as a measure of spatial accessibility to local amenities is misleading and may explain why research based on proximity-driven conceptualisations of access has shown discrepancies. Second, an extensive host of research has reported that a wide range of outlets' characteristics including prices policy (Drewnowski, Aggarwal et al. 2012), facilities provided (e.g. car park (Widener, Metcalf et al. 2011; Chen and Clark 2013)), and point-of-sale atmosphere (e.g. kid-friendly (Ayala, Mueller et al. 2005)) also inform the decision making process regarding where to shop and what to eat (Smith and Sanchez 2003; Krukowski, Sparks et al. 2013). Accordingly, contemporary research on the foodscape has mostly stood behind the assumption that individuals rationally evaluate food outlets on a set of attributes (e.g. price, location, services provided) and then patronize the option that will best accommodate their desire and means (financial, material, etc.) (Cannuscio, Hillier et al. 2014). Under that perspective, both the characteristics of individuals and the characteristics of food outlets interrelate to create the conditions of use. It has therefore been suggested that environmental and individual features should be looked at in a *relational approach* (Cummins, Curtis et al. 2007). Drawing from Penchansky and Thomas's work on access (Penchansky and Thomas 1981), current reflections on access have suggested to measure the level of access one has of a given food outlet type by assessing the 'fit' between the individuals' and outlets' characteristics. A good 'fit' was deemed to make a given type of outlet a potential candidate for use. When either healthy or unhealthy outlets were deemed potential candidates for use, then the foodscape was considered either health-promoting or health-detrimental, respectively.

Yet, in urban contexts, food retail is pervasive (Fielding and Simon 2011), and mobility facilitated (Miller 2007). Without dismissing food insecurity, which remains a major issue for some people, situations where *both* healthy *and* less-healthy food outlets are potential candidates for use are certainly common. In this case, is the foodscape's influence positive or negative on health behaviours? In sum, the question may not only be whether healthy and unhealthy food resources, taken separately, are potentially accessible, but also how likely healthy options are to be chosen in a situation where both healthy and unhealthy resources are potential candidates for use. Yet, we argue that current conceptual positions on access fail to provide comprehensive insights on the factors which push individuals to select a healthy rather than a less-healthy option (and vice-versa) when found in a position of choice. Overall, there is a need to bring further understanding of the decision making process for healthy and less-healthy food outlet choice.

1.3.2. Access and the question of alternatives: current positions and limitations

Individuals are often presumed to be engaged 'actively, rationally and creatively' with the foodscape (Cannuscio, Hillier et al. 2014), that is, 'act in their own self-interest with full awareness of how that self-interest is achieved' (Welsh and MacRae 1998). This means for consumers to objectively evaluate food outlets on a set of attributes and then patronize the best option given their preferences, means and constraints (Bhatnagar and Ratchford 2004). Put differently, food choices are assumed to describe a fully-informed preferential behaviour toward one (or a few) option(s) out of a larger field containing competing alternatives.

In the cases where consumers' primary concern(s) relate to questions of proximity, price, convenience, or point-of-sale atmosphere (or a combination of those), the place actually selected will be healthy only if this place is more advantageous with regard to these aspects than the less-healthy alternatives also evaluated. Rose et al. have therefore suggested that a sound conceptualisation of access should consider the *relative* assessment of healthy and unhealthy food outlets with regard to relevant criteria for choice (Rose, Bodor et al. 2009). In the cases where the healthfulness of food outlets is a concern, beyond questions of proximity, price, or convenience, the outlet selected will be healthy if the individual is inclined to prefer healthy behaviors, and unhealthy in the opposite case. Consequently, a comprehensive conceptualisation of access should also be informed by influences on motivation to shop/eat at healthy or less-healthy places. Inclination for healthy and less-healthy food options are commonly presumed to be shaped by genetic predispositions (Brown and Ogden 2004) and, throughout the life-course, by both the sociocultural (e.g. family (Benton 2004; Delormier, Frohlich et al. 2009), local residents (Delormier, Frohlich et al. 2009; Cannuscio, Hillier et al. 2014)) and the 'information' environments – the latter referring to food marketing and advertising (Glanz, Sallis et al. 2005). In sum, the dominant conceptual position of access is nurtured by two tenets. First, people consciously process information before they decide where and what to buy or eat (Cannuscio, Hillier et al. 2014). Second, they tend to opt for the option that is optimally satisfying, with regard to a set of consciously assessed outlet characteristics such as proximity, price, convenience, social atmosphere and healthfulness.

Although one cannot reasonably deny that outlet choice relies to some extent on a rational decision-making process, we argue that considering individuals as utility-maximizers with full awareness of how to achieve this maximisation is challenged in the view of two elements. First, maximising one's interest implies to have a clear idea about the relative priority one attaches to different store characteristics. Yet, there is little evidence that individuals are able to readily identify their own priorities when it comes to food purchase. In a study by Krukowski et al., surveyed individuals who were asked to spontaneously report the two most important factors for food store choice evoked most often proximity from home and price. Yet, among the very same group of people, freshness of meat and a well-maintained store were the two factors from a list of 49 factors including proximity and price that gathered the average highest ranking for importance in food store selection (Krukowski, Sparks et al. 2013). The fact that individuals rank factors for food store choice differently when those factors are considered spontaneously or as part of a list illustrates the complexity that surrounds the decision for food store choice in a context of many available options. In sum, choices tend to be satisfying, rather than optimal (Brown, 1993). Second, recent work in the field of environmental psychology and retail marketing suggests that the ability to exercise conscious and intentional choices is actually quite limited (Dijksterhuis, Smith et al. 2005; Cohen and Farley 2008). Laboratory and in-store experiments have demonstrated that food choice often unfolds unconsciously as a result of the mere perception of cues in the environment (Dijksterhuis, Smith et al. 2005; Cohen and Farley 2008). For instance, increased shelf space dedicated to a given food item is steadily followed by increased sales of this item (Curhan 1973; Curhan 1974; Chevalier 1975; Wilkinson, Mason et al. 1982; Desmet and Renaudin 1998; Eisend 2014), proving that supply drives consumers' behaviours. Relying on external cues is assumed to be an automatic mechanism naturally developed to ease the decision-making process through reduced brain involvement – 'involvement' here referring to feelings of interest, concern and enthusiasm held towards something (Beharrell and Denison 1995). This may be especially true nowadays; in the complex context food choices are made, what, how much and where to eat is rendered especially difficult to monitor (Bargh and Chartrand 1999; Wansink 2004). Returning to the example of shelf space driving sales, it has been suggested that if a product is given a large shelf space, it is more likely to be seen by customers and, in turn, purchased more frequently (Dreze, Hoch et al. 1995; Desmet and Renaudin 1998). Furthermore, shelf organization may signal item attractiveness and steer purchase decisions; items that receive more shelf space than other alternatives are thought to be more successful and hence more attractive (Eisend 2014). Thus, without dismissing the existence of fully-informed influences on the decision making process of where and what to shop/eat (e.g. price or proximity considerations), it may be fruitful to take some distance with the assumption of fully conscious food choices, and consider also the complementary influences that occur outside of conscious awareness (Dijksterhuis, Smith et al. 2005; Cohen and Farley 2008). In light of these elements, we may logically question whether the foodscape may unconsciously influence the decision to patronize a healthy place rather than a less-healthy one (and inversely).

Empirical research in very recent years has shown that the *relative* density of healthy and unhealthy food outlets around home is more strongly related to the healthfulness of dietary behaviours than *absolute* densities of either healthy or unhealthy outlets taken separately (Mason, Bentley et al. 2013). Overall, the higher the proportion of healthy stores, the higher fruit and vegetable purchases and intake (Mason, Bentley et al. 2013), the better the overall quality of diet (Mercille, Richard et al. 2012), and the lower the consumption of fast-food and soda (Babey, Wolstein et al. 2011). This invites the question of whether the extent to which the relative densities of healthy and unhealthy food outlets in individuals' living places may signal outlets' popularity and impact food purchase behaviours. Yet, the use and usefulness of relative densities of healthy and unhealthy outlets requires both better conceptual integration and more empirical evidence. This thesis attempts to fill this gap.

1.4. Thesis plan

The next chapter (Chapter 2) is a literature review of how the central concept of access to the foodscape has commonly been approached in public health nutrition. It concludes that there is a need to put in perspective and better articulate the various influences, conscious and less conscious, that push individuals to opt for a healthy or a less healthy food outlet when the foodscape offers multiple alternatives to choose from. Chapter 3 (Article # 1) proposes a novel conceptualisation of access to the foodscape. Specifically, it upholds the original idea that the relative distributions of healthy and unhealthy food outlets drives a normative message about where and what to buy/eat. Chapter 4 introduces two case studies directly inspired from our conceptual proposal. They consist in exploring the association between relative densities of healthy and unhealthy food outlets and fruit and vegetable intake. Chapter 4 includes an explanatory statement and a description of the research objective, research questions, and methods employed to answer them. Drawing on multiple secondary datasets pertaining to adult residents of five large Canadian cities, chapter 5 examines the association between the percentage of healthy outlets both in the residential (Article # 2) and in the non-residential (Article # 3) environments and fruit and vegetable intake. Finally, Chapter 6. and 7. respectively discuss the findings, identify the potential impact and limitations of this research, and conclude.

CHAPTER 2. LITERATURE REVIEW

2.1. The 'slippery' notion of access

2.1.1. Distinguishing real from potential access

Access is a complex concept lacking a clear and consensual definition (Penchansky and Thomas 1981). It has been indifferently referred to as a verb relating to the act of using a system, and as a noun referring to the potential for a system to be used (as in 'accessibility') (Guagliardo 2004). Recent literature on foodscape has usefully distinguished *real* (or *realized* or *actualised* (Guagliardo 2004)) from *potential* access (Zenk, Thatcher et al. 2014). On one hand, *real* access refers to the action of walking into a store or a restaurant to actually buy food or eat, and is directly measured by observing or surveying individuals' behaviours. On the other hand, *potential* access refers to the potential for a food resource to be used and is determined by assessing whether the conditions for using that resource are met. It implies to identify the factors enabling or restricting the use of an outlet, and disentangle the mechanisms explaining how individuals use the foodscape.

From a public health nutrition perspective, it is not so much where people actually go for food shopping, as the factors that shape where they shop for food which is meaningful (Chaix, Meline et al. 2013; Zenk, Thatcher et al. 2014). At a time when guidance for creating health-supportive food environments is lacking, identifying the factors which facilitate or restrict the use of healthy and unhealthy food outlets represents a promising avenue for research and policies (Story, Kaphingst et al. 2008).

N.B.: Because this thesis will focus on potential access, from now on and until the end of the document 'potential access' will be simply referred to as 'access' for ease of reading.

Actual use will explicitly be referred to using the full expression 'real access' to avoid confusion.

2.1.2. Earliest conceptual foundations of access

Earliest conceptual foundations of access inspired by 'gravity models' have drawn on the fundamental assumption that interest for a given facility (i.e. food outlet) declines with distance from home, especially due to 'frictions' of time and transportation costs (Pacione 1974; Brown 1989). Doing so, consumers have been assumed to use the nearest places from home that offer the required goods or service (i.e. foods). This perspective led a wide range of studies to approach the question of access to the foodscape exclusively from a spatial accessibility perspective (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012). They were motivated by the concern that individuals may opt for unhealthy food outlets for the simple reason that this outlet type was more readily accessible in the close vicinity of home than more distant healthy resources.

Accordingly, various methods, subjective or objective, have been adopted to assess the degree of spatial accessibility to either healthy or unhealthy food outlets (McKinnon, Reedy et al. 2009). With regard to subjective measures, researchers have drawn on individual perceptions of accessibility (Pearson, Russell et al. 2005; Caldwell, Miller Kobayashi et al. 2009; Sharkey, Johnson et al. 2010; Williams, Ball et al. 2010; Gustafson, Sharkey et al. 2011; Sohi, Bell et al. 2014), for instance, by asking participants whether they perceived certain types of food outlets to be within walking distance of their homes (Caspi, Kawachi et al. 2012). Studies using objective measures have mostly relied on proximity (i.e. distance) or density (i.e. number in a bounded area), using Geographic Information Systems (GIS). Proximity has variably been measured using travel time (Pearce, Witten et al. 2006; Burns and Inglis 2007; Pearce, Blakely et al. 2007; Jiao, Moudon et al. 2012) or metric distance to food stores - either

Euclidean (Laraia, Siega-Riz et al. 2004; Winkler, Turrell et al. 2006; Apparicio, Cloutier et al. 2007; Wang, Kim et al. 2007; Bodor, Rose et al. 2008; Murakami, Sasaki et al. 2009; Michimi and Wimberly 2010; Izumi, Zenk et al. 2011), Manhattan (Zenk, Schulz et al. 2005) or street-network based (Donkin, Dowler et al. 2000; Clarke, Eyre et al. 2002; Pearson, Russell et al. 2005; O'Dwyer and Coveney 2006; Jago, Baranowski et al. 2007; Liu, Wilson et al. 2007; Larsen and Gilliland 2008; Sharkey and Horel 2008; Smoyer-Tomic, Spence et al. 2008; Timperio, Ball et al. 2008; Pearce, Hiscock et al. 2009; Sharkey, Johnson et al. 2010; Thornton, Crawford et al. 2010; Williams, Ball et al. 2010; Gustafson, Sharkey et al. 2011; Caspi, Kawachi et al. 2012; Sharkey, Dean et al. 2013; Wedick, Ma et al. 2015). Density has usually referred to the number of food outlets within a certain perimeter from home. Some have relied on administrative boundaries such as census tract enclosing home (Morland, Wing et al. 2002). Others have used home-centered units of aggregation such as circular buffers (Laraia, Siega-Riz et al. 2004; Jeffery, Baxter et al. 2006; Winkler, Turrell et al. 2006; Wang, Kim et al. 2007; Bodor, Rose et al. 2008) or street-network buffers (Burdette and Whitaker 2004; Jago, Baranowski et al. 2007; Liu, Wilson et al. 2007; Smoyer-Tomic, Spence et al. 2008; Timperio, Ball et al. 2008; Paquet, Daniel et al. 2010; Thornton, Crawford et al. 2010; Williams, Ball et al. 2010) with a radius chosen to match the supposed distance individuals are ready to travel to get their food. Yet, in absence of consensus on what that distance is, various values roughly ranging from 100 meters to 5 miles have been used (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012). In short, finding appropriate and consistent criteria for defining geographic boundaries of spatial accessibility has proven challenging (Charreire, Casey et al. 2010).

Overall, the relationship between dietary behaviour and spatial accessibility to various food outlets has lacked consistent evidence both with objective and perceived measures (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012). Whereas increased spatial accessibility to healthy (Morland, Wing et al. 2002; Laraia, Siega-Riz et al. 2004; Rose and Richards 2004; Zenk, Schulz et al. 2005; Caldwell, Miller Kobayashi et al. 2009;

Michimi and Wimberly 2010) and unhealthy (Satia, Galanko et al. 2004; Timperio, Ball et al. 2008; Moore, Diez Roux et al. 2009; Gustafson, Sharkey et al. 2011) food sources have been associated with diets of better and lower nutritional quality respectively, many studies have found no associations (Burdette and Whitaker 2004; Rose and Richards 2004; Cummins, Petticrew et al. 2005; Simmons, McKenzie et al. 2005; Jeffery, Baxter et al. 2006; Bodor, Rose et al. 2008; Pearce, Hiscock et al. 2008; Turrell and Giskes 2008; Pearce, Hiscock et al. 2009; Thornton, Bentley et al. 2009; Jaime, Duran et al. 2011). Furthermore, the few studies that have investigated interventions bringing healthy food sources (e.g. supermarkets or grocery stores) in underserved residential areas did not provide convincing evidence that increased local availability of healthy food outlets would alter dietary behaviours of local residents (Cummins, Petticrew et al. 2005; Cummins, Flint et al. 2014).

Despite a lack of consistent evidence between spatial accessibility to food sources and dietary behaviour, it would be premature and potentially misleading to conclude that altering retail distribution may not impact health. Instead, the studies carried out to date have provided justification for a reinforced investigation of how and how much the distribution and type of food outlets shape dietary behaviours and health. Beyond the practical necessity for improved measurement of diet outcomes (Kirkpatrick, Reedy et al. 2014) and of exposure variables (Lytle 2009; McKinnon, Reedy et al. 2009; Burgoine, Alvanides et al. 2013), scholars have also called for an improved conceptualisation of access to the foodscape (Macintyre, Ellaway et al. 2002; Cummins, Curtis et al. 2007). Doing so requires to identify the elements of the foodscape that may influence dietary behaviours and the corresponding mechanisms (Entwisle 2007).

2.2. Is there only spatial accessibility in access?

In recent years, conceptual refinements of access have been driven by two considerations. First, individuals are mobile (Miller 2007) and do not systematically get their food in the vicinity of home (Day 1973; Inagami, Cohen et al. 2006; Hillier, Cannuscio et al. 2011; Kerr, Frank et al. 2012). As individuals do not always shop locally, other dimensions beyond home proximity should be accounted for when conceptualising access. Second, individuals do not experience the foodscape in a same way (Thompson, Cummins et al. 2013). A sound conceptualisation of access should therefore consider how both individual and environmental characteristics interrelate and create the conditions for use (Cummins, Curtis et al. 2007).

2.2.1. Individuals' mobility or the stretching opportunities for food shopping

Individuals' daily mobility has been growing, helped by the advent of transportation and information technologies (Miller 2007). Individuals travel on a daily basis through and beyond the invisible boundaries traditionally used by researchers to delineate units of aggregation and derive measures of access (Matthews 2010). Surely, movement across space is constrained by certain spatial boundaries, since individuals have to compose with their mobility potential (Shareck, Kestens et al. 2014), depending on both intrapersonal (e.g. physical disability) and structural (e.g. public transport availability) factors. The extent of daily mobilities is therefore subject to variation among populations. For instance worse-off (Hanson and Hanson 1981; Murakami and Young 1997; Clifton 2004), the elderly (Tacken and Rosenboom 1998; Inagami, Cohen et al. 2007; Lord, Després et al. 2011) and women (Hanson and Hanson 1980; Hanson and Hanson 1981; Hanson and Johnston 1985; Frändberg and Vilhelmson 2011) have been reported to travel shorter distances on a daily basis than their counterparts. Yet, overall, access may not be as confined and bounded as we have tended to feature it (Matthews 2010). Defining access exclusively as a measure of spatial accessibility to local resources is misleading and may explain why research standing behind that conceptual position has shown discrepancies (Chaix, Merlo et al. 2009; Perchoux, Chaix et al. 2013).

As people move throughout the city, additional opportunities to get food present to themselves, mostly because of cumulative exposure (Kestens, Lebel et al. 2010), but also because densities of food outlets experienced away from home tend to be higher compared to at home (Kestens, Lebel et al. 2010; Burgoine and Monsivais 2013; Crawford, Jilcott Pitts et al. 2014; Clary and Kestens Unpublished results). As a result, daily mobility tends to considerably stretch the range of food shopping possibilities (Widener, Farber et al. 2013). Empirical evidence attests that individuals actually use food shopping opportunities located far beyond the home vicinity (Day 1973; Inagami, Cohen et al. 2006; Hillier, Cannuscio et al. 2011; Kerr, Frank et al. 2012). They do not necessarily do so in order to escape a scarcity of supply in the vicinity of home (Day 1973; Cummins, Petticrew et al. 2005; Drewnowski, Aggarwal et al. 2012; Cannuscio, Tappe et al. 2013). Instead, they bypass closer food outlets for more distant but more desirable destinations. Even worse-off individuals, presumed to be limited in their mobility potential (Shareck, Frohlich et al. 2014), are actually reported to take advantage of food stores located far beyond their residential neighbourhood (Hillier, Cannuscio et al. 2011; Aggarwal, Cook et al. 2014). Cannuscio et al. highlighted that distance traveled to reach the primary shopping place did not differ significantly by socioeconomic status (Cannuscio, Tappe et al. 2013). Overall, consumers do not seem to strictly minimize traveled distances (Dellaert, Arentze et al. 1998).

2.2.2. Proximity… and the many other outlet characteristics influencing food outlet choice

When making decisions about where to buy food, consumers evaluate the interest of food sources on complementary characteristics beyond location. There is evidence that food store choice is made regarding financial considerations (Ayala, Mueller et al. 2005; Krukowski, Sparks et al. 2013; Cannuscio, Hillier et al. 2014). For instance, Drewnowski et al. have shown that the nearest food stores from home tend to be bypassed for more distant but cheaper options (Drewnowski, Aggarwal et al. 2012). Consistent with these findings, supermarkets have been reported as a privileged outlet for primary food shopping at the expense of closer places (Rose and Richards 2004; White, Bunting et al. 2004; Ayala, Mueller et al. 2005; D'Angelo, Suratkar et al. 2011; Cannuscio, Tappe et al. 2013), especially due to their relatively low prices (Pacione 1974; Chung and Myers 1999; White, Bunting et al. 2004; Rose, Bodor et al. 2009). Given the essential nature of feeding and the frequency with which individuals need to eat, food represents an unescapable and considerable expenditure for families. This may help understand why travel costs may be sacrificed to the interest of more distant, but more financially profitable options.

Several studies have further demonstrated that factors pertaining to the convenience of a store were also relevant to store selection. For instance, facilities to complete shopping quickly, store opening hours, and presence of a parking area have all been reported as influencing factors for deciding where to shop (Ayala, Mueller et al. 2005; Helgesen and Nesset 2010; Krukowski, Sparks et al. 2013).

Now, food shopping is more than an instrumental activity for maintenance of the household. Cultural and symbolic aspects have further been shown to complementarily influence the decision about where to shop for food (Day 1973). For instance, individuals have reported to selectively shop at stores that aligned with their self-perceived socioeconomic and cultural status, that is where they had positive interactions with customers and personnel (Ayala, Mueller et al. 2005; Cannuscio, Weiss et al. 2010; Helgesen and Nesset 2010; Cannuscio, Hillier et al. 2014) and where culturally congruent foods were available (Wang, MacLeod et al. 2007; Cannuscio, Tappe et al. 2013; Cannuscio, Hillier et al. 2014). The search for social interactions may also sometimes outweigh the primary purpose of food purchasing (Cannuscio, Weiss et al. 2010).

Hence, in recent years, conceptual refinements of access have increasingly recognised the multiple influences that impact the way individual use the foodscape (Cummins, Curtis et al. 2007; Story, Kaphingst et al. 2008).

2.2.3. The multidimensional concept of access

Individuals tend to use the various resources provided by their surroundings differently, because they have different capacities and motivations to do so (Entwisle 2007; Frohlich and Potvin 2008). For instance, a person may judge the delicatessen store next door his/her house inaccessible, as prices may be considered too high relatively to his/her income, and therefore shop at the corner store further down the street which proposes cheaper options. Yet, this very same delicatessen shop may be frequently used by a wealthier neighbour whose generous pension makes financial considerations less relevant. People are selective with their foodscape in a manner that tend to accommodate their means, constraints and preferences (Entwisle 2007). Consequently, it is neither the location, nor the price, the type of service available, or the atmosphere *in itself* that will help designate a food store as a potential candidate for use. Instead, it is a combination of all those characteristics *in relation to* individuals' ability and desire to accommodate to them (Cummins, Curtis et al. 2007). Individuals' trade-off between value-for-money and distance, or between convenience and friendliness of staff, for example, is likely to vary (Smith and Sanchez 2003). In sum, both individual and foodscape characteristics interrelate to create the conditions of use.

Borrowing from Penchansky and Thomas' work on access to healthcare (Penchansky and Thomas 1981), most recent conceptualisations of access have built upon five dimensions of 'fit' between individuals' capacity and predispositions to use the foodscape, and the actual characteristics of food outlets. These five dimensions, known as *availability*, *spatial accessibility*, *affordability*, *accommodation*, and *acceptability* (e.g. (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012; Cannuscio, Hillier et al. 2014)), have been transposed from Penchansky and Thomas' definition (Penchansky and Thomas 1981) (with a few "adjustments" discussed further in this paragraph). 1) *Availability* is commonly referred to as the actual existence of the outlet type of interest, and is mainly operationalised as the objective or perceived number of this outlet type within a certain perimeter (Morland, Wing et al. 2002; Jeffery, Baxter et al. 2006; Bodor, Rose et al. 2008; Turrell and Giskes 2008; Moore, Diez Roux et al. 2009; Murakami, Sasaki et al. 2009; Zenk, Lachance et al. 2009; Williams, Ball et al. 2010; Gustafson, Sharkey et al. 2011; Jennings, Welch et al. 2011). 2) *Spatial accessibility* usually represents the relationship between the location of food resources and individuals' ability to reach that location, accounting for transportation resources and travel time, distance and cost. It has mostly been assessed in terms of distance perceived (Inglis, Ball et al. 2008) or objectively measured (Laraia, Siega-Riz et al. 2004; Pearce, Hiscock et al. 2008; Turrell and Giskes 2008; Pearce, Hiscock et al. 2009; Zenk, Lachance et al. 2009; Michimi and Wimberly 2010; Sharkey, Johnson et al. 2010; Williams, Ball et al. 2010; Gustafson, Sharkey et al. 2011). 3) *Affordability* is the relationship between prices and the individuals' ability to pay. It has been operationalised, for instance, as participants' perceptions of produce affordability (Zenk, Schulz et al. 2005; Inglis, Ball et al. 2008; Sharkey, Johnson et al. 2010; Williams, Ball et al. 2010) or store auditors' accounts of food prices (Pearson, Russell et al. 2005; Zenk, Lachance et al. 2009). 4) *Accommodation* represents the relationship between the manner in which the food resources are organized to accept individuals and individuals' ability to accommodate to these factors; it has variously designated hours of operation (Thornton, Crawford et al. 2010; Chen and Clark 2013), car-/bike-park and walk-in facilities (Widener, Metcalf et al. 2011; Chen and Clark 2013), as well as acceptance of informal credit payment (Horowitz, Colson et al. 2004). 5) *Acceptability* refers to one's feeling of socio-cultural harmony (Day 1973). This concept builds on the idea that food places provide the structuring context for social relations (Feagan 2007) and has been operationalised as a measure of socio-cultural harmony both regarding the staff (Cannuscio, Weiss et al. 2010), the customers (Cannuscio, Hillier et al. 2014) and the products sold (Wang, MacLeod et al. 2007; Cannuscio, Hillier et al. 2014).

In practice, empirical studies have assessed the extent to which one type of outlet (either healthy or unhealthy) was meeting the condition for access with regard to one or a few dimensions enumerated above (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012). Unhealthy outlet types of interest have generally included fast-food restaurants (Morland, Wing et al. 2002; Burdette and Whitaker 2004; Baker, Schootman et al. 2006; Jeffery, Baxter et al. 2006; Burns and Inglis 2007; Liu, Wilson et al. 2007; Smoyer-Tomic, Spence et al. 2008; Timperio, Ball et al. 2008; Turrell and Giskes 2008; Moore, Diez Roux et al. 2009; Pearce, Hiscock et al. 2009; Thornton, Bentley et al. 2009; Paquet, Daniel et al. 2010; Jennings, Welch et al. 2011) and convenience stores (Morland, Wing et al. 2002; Laraia, Siega-Riz et al. 2004; Liu, Wilson et al. 2007; Pearce, Hiscock et al. 2008; Timperio, Ball et al. 2008; Zenk, Lachance et al. 2009; Izumi, Zenk et al. 2011), while healthy ones have mainly included supermarkets (Donkin, Dowler et al. 2000; Morland, Wing et al. 2002; Laraia, Siega-Riz et al. 2004; Rose and Richards 2004; Pearson, Russell et al. 2005; Zenk, Schulz et al. 2005; Baker, Schootman et al. 2006; O'Dwyer and Coveney 2006; Apparicio, Cloutier et al. 2007; Burns and Inglis 2007; Liu, Wilson et al. 2007; Bodor, Rose et al. 2008; Larsen and Gilliland 2008; Moore, Diez Roux et al. 2008; Moore, Diez Roux et al. 2008; Pearce, Hiscock et al. 2008; Smoyer-Tomic, Spence et al. 2008; Timperio, Ball et al. 2008; Zenk, Lachance et al. 2009; Michimi and

Wimberly 2010; Sharkey, Johnson et al. 2010; Thornton, Crawford et al. 2010; Williams, Ball et al. 2010; Jennings, Welch et al. 2011), grocery stores (Morland, Wing et al. 2002; Laraia, Siega-Riz et al. 2004; Zenk, Lachance et al. 2009; Gustafson, Sharkey et al. 2011; Izumi, Zenk et al. 2011), and fruit and vegetable stores/markets (Timperio, Ball et al. 2008; Williams, Ball et al. 2010; Izumi, Zenk et al. 2011; Jennings, Welch et al. 2011). However, the choice to look at one outlet type over another has overall lacked sound justification.

In their original work on healthcare access, Penchansky and Thomas defined *availability* strictly as “the relationship of the volume and type of existing services (and resources) to the clients' volume and types of needs”. This notion of *needs* appears central to their definition of availability - and, in turn, access - as it provides guidance on *what resources* should be looked at when access concerns are raised. Healthcare resources to which access should be assessed are those which people *need*. Yet, “access to what?” is a question that has been rather absent from the literature on foodscape access. This may explain why the choice to look at one given food outlet rather than another one seems rather arbitrary. In sum, the public health nutrition field has recently been valuably marked by a shift from a purely geography-driven definition of foodscape access to a more inclusive and comprehensive approach. Yet, we suggest that there is still room for improvement in our conceptualisation of access, especially regarding what resources should be looked at when foodscape access is put in relation to dietary behaviors, and the reasons why.

2.3. Access to healthy outlets, to unhealthy outlets or to both? The disregarded question of alternatives

With regard to the healthcare system, the linkage between a given health disorder, the corresponding need(s) and the required resource(s) is somehow straightforward, because it is dictated by the health system itself. For instance, nobody would reasonably contest that an individual suffering with eye disorders (initial concern) is in need for an eye examination/care (corresponding need), and that eye services represent the most appropriate resource (required resource) to use in order to tackle that issue. Thus, if we meant to assess how much the healthcare system has a positive or detrimental impact on an individual suffering from eye disorders, the focus would be on eye services, and studies would, in turn, assess whether eye services were spatially accessible, affordable, convenient and acceptable.

However, unlike the healthcare system, the foodscape is an exclusively market-guided system whose economic rules are established in the primary aim of its own economic viability (Evans, Bridson et al. 2008), not consumers' health. It encloses both healthier (e.g. fruit and vegetable stores) and unhealthier (e.g. fast-food restaurants) food sources. Thus, depending on the selected options, individuals convert their need for food into either healthy or less healthy behaviours. Assuming that individuals tend to 'maximise' health benefits associated with consumption of food – or, put differently, assuming that food choices are driven by a *need* for healthy food, then, we might expect healthy resources to be used when accessible. Under that perspective where the default choice is presumed to be a healthy one, questioning foodscape influences on dietary behaviors could be restricted to assessing access to healthy food sources. And following along the same lines, an environment offering at least one spatially accessible, affordable, convenient and acceptable healthy food outlet could be deemed health-promoting, regardless of the access the environment may concomitantly offer to unhealthy outlets. Yet, there is evidence that individuals do not use unhealthy food sources for the mere reason that healthier options are non-accessible (Kubik, Lytle et al. 2003; Fox, Gordon et al. 2009; Cohen, Sturm et al. 2010; Yeh, Matsumori et al. 2010). That is, the 'need for healthy food' decreed by health authorities is a public health construct more than a universally accepted reality.

This statement has important consequences on the way access should be conceptualised. First, it appears misleading to stand behind the position that healthy dietary behaviours are constrained exclusively by how accessible healthy resources are – and inversely that unhealthy dietary behaviours are constrained exclusively by how accessible unhealthy resources are. Rather, this invites to better considering what the foodscape has to offer as a whole. Second, for the field to move forward, it appears that a sound conceptualisation of access should better account for the various influences which push individuals to opt for a healthy food outlet or a less-healthy alternative when in a context of multiple, healthy and less healthy, choices. This led us to develop a novel conceptualisation of access to the foodscape. This conceptual proposal is presented in the following chapter.

CHAPTER 3. CONCEPTUAL PROPOSAL

ARTICLE 1

Title: Between exposure, access and use: reconsidering foodscape influences on dietary behaviours through the question of alternatives

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ABSTRACT

In westernized cities characterized by pervasive food retail and facilitated individual mobility, potential accessibility to both “healthy” and “unhealthy” outlets may be a greater reality than food deserts. Yet, current positions on access lack insights on the environmental factors that may push individuals to opt for healthy options in the competitive presence of less healthy alternatives (and inversely). With intent to address this gap, we propose novel conceptual underpinnings on how the foodscape shapes health behaviours. We build on the fundamental position that outlet’s attributes (e.g. location, prices) may render “healthy” and “unhealthy” outlets differentially accessible to individuals seeking to maximize their self-interests. However, we argue that people’s limited ability to acquire and effectively utilize the information available in their environment gives rise to complementary environmental influences. Particularly, we highlight how the foodscape may stimulate automatic biological interests for unhealthy options, implicitly suggest what outlet’s type is appropriate to patronize, and encourage the development of routines. We conclude with implications for research.

BACKGROUND

In recent decades, interest in food environment influences on dietary behaviours has grown in a context of multiple observations. First, the limited impact on populations' health of education programs has pushed the field of public health to move from a behavioural change perspective to an ecological approach emphasizing contextual influences on health (Green, Poland et al. 2000; Story, Kaphingst et al. 2008). Second, the development of advanced technologies in health geography (e.g. Geographic Information Systems (GIS)) has facilitated the wide-scale production of environmental variables (Moore and Carpenter 1999). Finally, in westernised cities where food is mostly acquired through market-guided retail and catering systems (Eckert and Shetty 2011), linkage between food environment and dietary behaviours makes intuitive sense. With the exception of some marginal distribution channels like community gardens, accessing food is conditional upon accessing food outlets (i.e. retail stores and restaurants). Commonly referred to as 'community nutrition/food environment' (Glanz, Sallis et al. 2005; Lake, Burgoine et al. 2010), or more simply 'foodscape' (Winson 2004), food outlets have therefore often been used as the basic unit of observation for assessing environmental influences on dietary behaviours (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012). Because in-store supply has been shown to drive purchase (Curhan 1973; Curhan 1974; Chevalier 1975; Wilkinson, Mason et al. 1982; Desmet and Renaudin 1998; Black, Moon et al. 2014; Eisend 2014), outlets providing a wide range of healthy foods (e.g. fruit and vegetable), like supermarkets (chain, non-chain, ethnic), grocery stores, and fruit and vegetable stores (Lewis, Sloane et al. 2005; Rose, Bodor et al. 2009; Reedy, Krebs-Smith et al. 2010; Ohri-Vachaspati, Martinez et al. 2011; Black, Ntani et al. 2014) have often been considered "healthy" (Sallis, Nader et al. 1986; Horowitz, Colson et al. 2004; Ohri-Vachaspati, Martinez et al. 2011; Cannuscio, Tappe et al. 2013; Black, Ntani et al. 2014). Inversely, convenience stores and fast-food restaurants have been termed "unhealthy". However, the way the distribution of these healthy and less-healthy outlet types shape dietary behaviours remains unclear (Giskes, Kamphuis et al. 2007; Feng, Glass et al. 2010; Caspi, Sorensen et al. 2012).

The foodscape is fundamentally assumed to influence diet by enabling or limiting the use of healthy and unhealthy food outlets (Story, Kaphingst et al. 2008). Accordingly, research has focused on *potential* access – i.e. the potential for outlets to be used, and assessed whether the conditions for using certain outlet types from healthy to less-healthy were met. People are selective with the foodscape and commonly presumed to use outlets in a manner that maximises their self-interests (Bhatnagar and Ratchford 2004; Entwisle 2007; Cannuscio, Hillier et al. 2014). Accordingly, it has been argued that it is not the attributes of an outlet per se that designates that outlet as a potential candidate for use, but rather those attributes *in relation to* individuals' propensity for, and desire to, accommodate them - what has been described in Cummins' *relational approach* (Cummins, Curtis et al. 2007). Put differently, both individual and foodscape characteristics interrelate to create the conditions of use (Cummins, Curtis et al. 2007; Cannuscio, Hillier et al. 2014). Borrowing from Penchansky and Thomas' work on access to healthcare (Penchansky and Thomas 1981), recent conceptualisations of potential access have built on five dimensions of interrelation or 'fit' (see for instance (Caspi, Sorensen et al. 2012; Cannuscio, Hillier et al. 2014)): 1/ Availability, as the existence of adequate supply of food outlets; 2/ Spatial accessibility, as the relationship between the location of food resources and the location of individuals, accounting for transportation resources and travel time, distance and cost; 3/ Affordability, as the relationship between prices and the clients' ability to pay; 4/ Accommodation, as the relationship between the manner in which the food resources are organized to accept customers (e.g. hours of operation (Chen and Clark 2013), car-/bike-park and walk-in facilities (Widener, Metcalf et al. 2011; Chen and Clark 2013), informal credit payment (Horowitz, Colson et al. 2004)) and the customers' ability to accommodate these factors; 5/ Acceptability, as the feeling of socio-cultural harmony (Day 1973) with both staff (Cannuscio, Weiss et al. 2010), customers (Cannuscio, Hillier et al. 2014), and the products sold (Wang, MacLeod et al. 2007; Cannuscio, Hillier et al. 2014)

In practice, empirical studies have explored the extent to which *either* healthy *or* unhealthy outlets taken separately were meeting conditions for access with regard to one or more of the dimensions enumerated above (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012). This approach has allowed the identification of situations where individuals lack access to healthy outlets *or* have a high access to unhealthy outlets, given rise to a large body of literature on "food deserts" (e.g. (Pearson, Russell et al. 2005; Smoyer-Tomic, Spence et al. 2006; Morton and Blanchard 2007)) and "food swamps" (Rose, Bodor et al. 2010; Fielding and Simon 2011), respectively. But what about when both healthy and unhealthy outlets meet criteria for potential access and are therefore possible candidates for use? In such case, is the foodscape influence positive or negative on dietary behaviours? In urban contexts of pervasive food retail (Rose, Bodor et al. 2009; Cohen, Sturm et al. 2010; Fielding and Simon 2011) and facilitated mobility (Miller 2007), for a wide range of the population, an abundance of choice from healthy to less-healthy options, may be a greater reality than food deserts. Yet, current positions on access lack insights on factors that push individuals to opt for a healthy option in the simultaneous presence of less healthy alternatives (and inversely). We argue that our understanding of foodscape influences on dietary behaviours would benefit from better considerations of the decision-making process for food outlet choice when various options, healthy and less-healthy, are possible. There is experimental evidence that contextual cues unconsciously influence healthy and unhealthy food choices, for instance, due to their capacity to stimulate biological interests for high-calorie foods (Cohen and Farley 2008), or through their normative dimensions (e.g. portion size drives the volume of intake (Rolls, Morris et al. 2002; Diliberti, Bordi et al. 2004; Rolls, Roe et al. 2004)). This has led us to question how much the foodscape might shape, beyond the practical question of potential access raised above, individuals' choices regarding where and what to buy/eat. With intent to address this gap, we draw from literature in retail marketing, environmental psychology and geography to propose novel conceptual underpinnings on how the foodscape shapes dietary behaviours. Those are synthetized in the conceptual framework presented in figure 1 and described below. We conclude with implications for research.

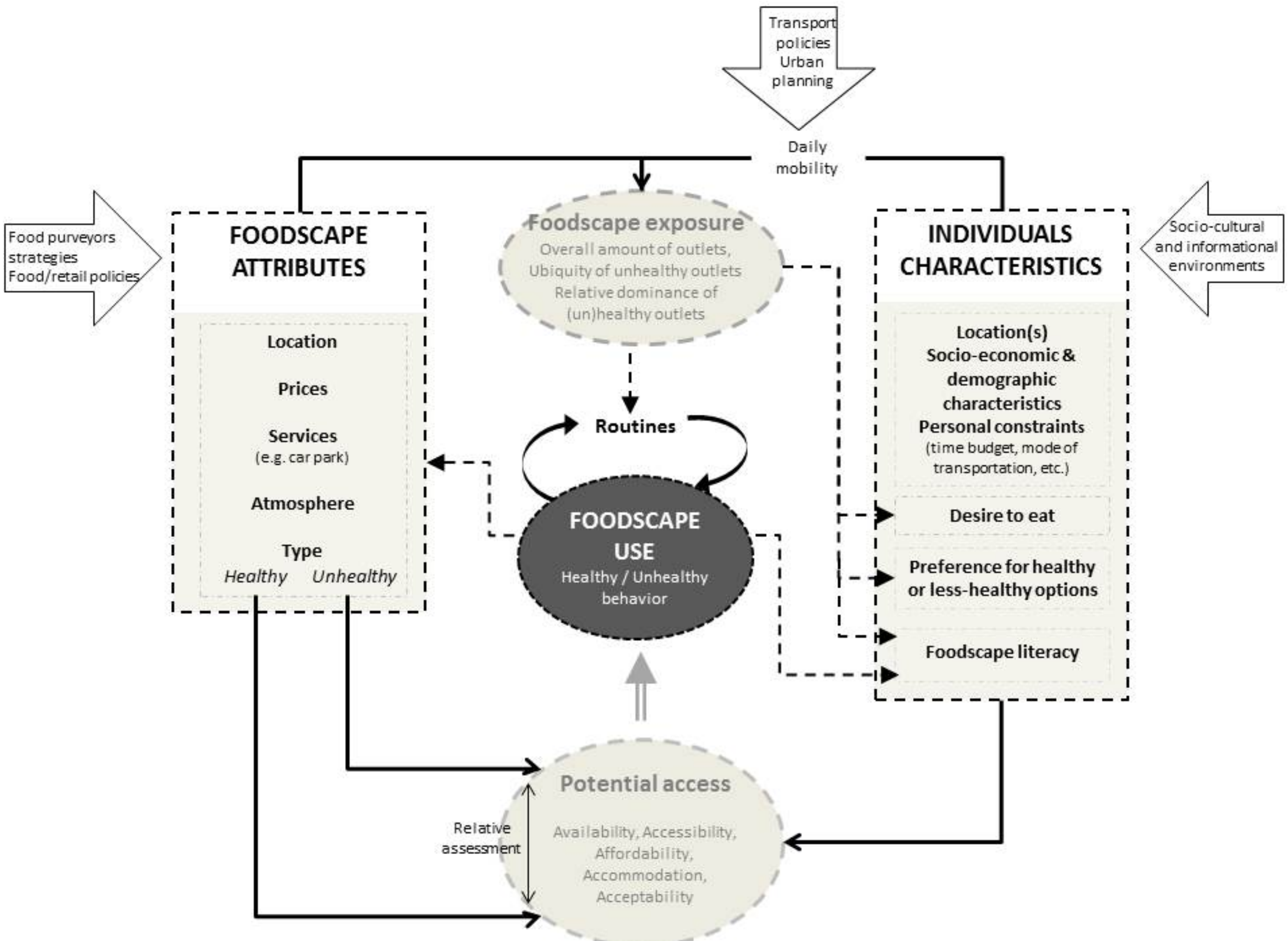

Figure 1 Conceptual framework depicting foodscape influences on dietary behaviours

Access and the disregarded question of alternatives

Food store choice describes a preference toward one (or a few) outlet(s) from a larger set of competing alternatives (Bhatnagar and Ratchford 2004). Common in research on foodscape is the idea that individuals are 'actively, creatively and rationally' engaged with the foodscape (Bhatnagar and Ratchford 2004; Cannuscio, Hillier et al. 2014), that is, to quote Welsh et al. 'act in their own self-interest with full awareness of how that self-interest is achieved' (Welsh and MacRae 1998). Individuals are assumed to evaluate food outlets on a set of attributes and then patronize the optimal option (Bhatnagar and Ratchford 2004). So what are the implications here for health behaviours? If individual choice is driven by the five dimensions of access highlighted above alone, then, healthy outlets will be preferred over less-healthy alternatives if they are *more* satisfying with regard to those dimensions. For instance, a cost-conscious family will certainly opt for the outlet which will minimize her expenditures. That restaurants serving healthy foods are, in absolute terms, affordable may be outweighed by the fact that fast-food restaurants are overall *more* affordable. Thus, a sound conceptualisation of access needs to account for the competitive nature of alternatives (Bhatnagar and Ratchford 2004). Not only should the attributes of a given outlet type and individuals' characteristics be considered using a relational approach, so too should the attributes of potential alternatives. Rose et al. have been among the first to suggest that our conceptualisation of access should involve the *relative* assessment of healthy and unhealthy outlets (Rose, Bodor et al. 2009).

Proximity, price, convenience, and acceptability notwithstanding, the healthfulness of an outlet can be a criterion of choice in itself. For instance, Cannuscio et al. have shown that shoppers tend to choose supermarkets that offer more healthful foods (Cannuscio, Tappe et al. 2013). Returning to our example, the cost-conscious family may prioritise the nutritional quality of food alongside its cost, and decide to eat in an affordable healthy restaurant despite the availability of cheaper but less-healthy alternatives.

Preference may be in favor of healthy or inversely, less-healthy options. These inclinations are commonly assumed to be shaped by genetic predispositions (Steiner 1979; Rosenstein and Oster 1988), and throughout the life-course by both the sociocultural (e.g. family (Benton 2004; Delormier, Frohlich et al. 2009), local community (Delormier, Frohlich et al. 2009; Cannuscio, Hillier et al. 2014)) and the information (e.g. food commercials (Boyland, Harrold et al. 2011)) environments. Thus, a sound conceptualisation of access should also involve consideration of the influences that may push individuals to favor a healthy or less-healthy options, regardless of the proximity, price, convenience and acceptability of outlets (Story, Kaphingst et al. 2008).

Now, although one may reasonably argue that outlet choice relies to some extent on a rational decision-making process, we argue that considering individuals as utility-maximizers with full awareness of how to achieve this maximisation is challenged in the view of two elements. First, to make the best use of the foodscape, individuals would need all the relevant information about all outlets' attributes (Welsh and MacRae 1998). Yet, individuals are not fully-knowledgeable about the environment (Milligan 1998). Their choice inevitably operates within the limit of their knowledge about the foodscape (Gillespie and Johnson-Askew 2009). Wang et al. reported that, in the context of new grocery store implementation, among locals who did not shop at the new store, 40% were not aware that the store existed (Wang, MacLeod et al. 2007), suggesting that ignorance may have been a barrier to actual use. Alongside social (e.g. friends, colleagues) and information (e.g. TV advertising) environments (Flamm, Jemelin et al. 2008), knowledge about the foodscape (or 'foodscape literacy') can be gained through foodscape actual use, but also through foodscape exposure – foodscape exposure here referring to the food outlets with which individuals coexist or have coexisted at some point in space and time (Kwan 2009). As people move throughout the city, they cumulate exposure to a considerable amount of food outlets (Kestens, Lebel et al. 2010; Burgoine and Monsivais 2013; Crawford, Jilcott Pitts et al. 2014; Clary and Kestens Unpublished results), thus gaining knowledge about their food environment (Flamm, Jemelin et al. 2008). Exposure should not be confounded with potential access. On one hand, individuals may get exposed to outlets that, however, remain inaccessible, because one or more conditions for access are not met (e.g. affordability). On the other hand, an outlet may be a potential candidate for use without individuals having ever been exposed to it. This may be the case of outlets that individuals have heard of through relatives or advertising.

The second element that challenges the basic assumption that individuals are utility-maximizers acting with full-awareness comes from laboratory and in-store experiments that have demonstrated the power of environmental cues to unconsciously shape dietary behaviours (Ilmonen 2001; Dijksterhuis, Smith et al. 2005; Herman and Polivy 2005; Cohen and Farley 2008). Relying without much deliberation on external food cues (i.e. food-relevant stimuli) is assumed to be a mechanism naturally developed to ease the decision-making process through reduced brain-involvement – 'involvement' here referring to feelings of interest held towards something (Beharrell and Denison 1995). This may be especially true nowadays. In the complex context in which food choices are made, what, how much, and where to eat is rendered especially difficult to monitor (Bargh and Chartrand 1999; Wansink 2004).

In the next paragraphs, we explore in turn three types of mechanisms through which the foodscape may influence dietary behaviours, without much individual control.

Biological beings or foodscape's propensity to stimulate food desire

Humans appear to have an innate liking for sweet and salty flavours, and energy-dense foods (Drewnowski and Greenwood 1983; Birch 1999), although this genetic predisposition tends to evolve with age due to environmental influences (e.g. social, cultural) (Desor, Greene et al. 1975; Birch 1999). Moreover, food cues provoke an automatic desire for eating (Wansink, Painter et al. 2006; Cohen and Farley 2008), regardless of appetite (Cornell, Rodin et al. 1989), meal setting (de Castro and Brewer 1992), and whether the food actually tastes good (Wansink and Kim 2005). Human beings can bring eating under control with more or less ease depending on some personality traits (e.g. reward-sensitivity (Beaver, Lawrence et al. 2006; Davis, Patte et al. 2007)). But generally, the amount of effort required to refrain from eating when food is present is substantial (Baumeister, Bratslavsky et al. 1998).

In westernised societies, unhealthy food stores using high-calorie food cues on outdoor walls for enticing passers-by (French, Story et al. 2001; Heinrich, Li et al. 2012) have become ubiquitous (Kestens, Lebel et al. 2010; Fielding and Simon 2011; Burgoine and Monsivais 2013). Accordingly, one may rightly query to what extent unhealthy stores act as consumption-reminders and activate a passer-by's desire to patronise the foodscape. Qualitative studies have reported that cravings and impulse purchases of snack foods are associated with fast food (Lucan, Barg et al. 2010) and convenience stores (Cannuscio, Hillier et al. 2014). Evidence of a direct relationship between exposure to unhealthy food stores and unhealthy diet remains, however, limited (Caspi, Sorensen et al. 2012). Among possible reasons is that the ubiquitous presence of unhealthy outlets may lead to relatively uniform levels of exposure across populations, precluding the detection of any effect in cross-sectional studies. Interestingly, the only (to our knowledge) large-scale longitudinal study which used repeated measures of both foodscape and diet over 15 years, has provided evidence that greater exposure to fast-food restaurants around home promote greater fast-food consumption (Boone-Heinonen, Gordon-Larsen et al. 2011). These findings were limited to low-income men, however. Differential responsiveness to food cues actually provides a second plausible explanation for the lack of consistency in quantitative studies. Consistent with this assumption, Paquet et al. found a positive relationship between exposure to fast-food restaurants and fast-food consumption only for individuals with high reward-sensitivity (Paquet, Daniel et al. 2010). Ultimately, desire for food activated by surrounding food cues may not translate in outlet patronage simply because outlets remain inaccessible (e.g.: due to a lack of financial resources or time).

Social beings or foodscape's normative dimension

The foodscape is not exogenous and predetermined. Outlets owe their existence to their economic viability, which is itself highly dependent on consumers' patronage. An area abundantly supplied with unhealthy food outlets witnesses that those unhealthy outlets are actually used for food purchases, whether their use is constrained by a lack of access to healthier alternatives, unconsciously stimulated by exposure to unhealthy outlets, or consciously favored by individuals. In this sense, the overtime make-up of the foodscape is a materialised reflection of consumers' patronage behaviours. Now, there is evidence that individuals tend to rely on environmental cues to gauge what it is socially appropriate to eat, referred to as *norms of appropriateness* (Herman, Roth et al. 2003). Benchmarks of appropriateness can be derived from environmental cues (Herman, Roth et al. 2003; Burger, Bell et al. 2010) either by denoting the popularity of a product (e.g. presence of a large number of empty wrappers (Robinson, Thomas et al. 2014)) or through their authoritative nature. For instance, people served larger portions of foods (e.g. pasta (Rolls, Morris et al. 2002; Diliberti, Bordi et al. 2004), potato chips (Rolls, Roe et al. 2004), popcorn (Wansink and Kim 2005), or soup (Wansink, Painter et al. 2005)) have been shown to eat more compared to individuals served smaller portions, probably because individuals place decisions about their consumption in the hands of the 'authority figure' who provides the food (Herman, Roth et al. 2003). Yet, how much the foodscape *itself* may provide benchmarks as to where buying food or eating has been disregarded.

There is evidence that the proportion of healthy stores around home, the higher fruit and vegetable purchase and intake (Mason, Bentley et al. 2013; Clary, Ramos et al.

2014), the better the overall quality of diet (Mercille, Richard et al. 2012), and the lower the consumption of fast-food and soda (Babey, Wolstein et al. 2011). These findings are consistent with the idea that the foodscape sends messages on the 'normal' or 'appropriate' choice to do. Owing to their cross-sectional design, these studies do not rule out the possibility of residents simply modifying their local environment through their food store choice. Yet, research has extensively shown that many individuals conduct their primary food shopping beyond the vicinity of the home (Day 1973; Whelan, Wrigley et al. 2002; Inagami, Cohen et al. 2006; Shaw 2006; Zandbergen and Chakraborty 2006; Hillier, Cannuscio et al. 2011; Chaix, Bean et al. 2012; Drewnowski, Aggarwal et al. 2012; Kerr, Frank et al. 2012; Cannuscio, Tappe et al. 2013; Krukowski, Sparks et al. 2013; Aggarwal, Cook et al. 2014; Cannuscio, Hillier et al. 2014). If they shop further away but their dietary behaviours reflect the overall nature of their local environment, this may simply be because norms of appropriateness may have been internalized. For instance, Moore et al. found that the density of fast-food restaurants around the home was not associated with patronising fast-food restaurants near the home. Yet the odds of having a healthy diet decreased by 12%–17% for every standard deviation increase in fast-food residential exposure (Moore, Diez Roux et al. 2009). These findings firstly suggest that foodscape normative influences are potentially spatially and temporally distinct from food purchasing/eating episodes. Along this line, Herman et al. differentiated situation-specific from person-specific norms (Herman and Polivy 2005). While the former refers to norms that may be inferred from the situation in which a food choice is made, the latter occurs when norms are internalized through past experiences. These findings also lead to the question of whether the foodscape around home would have a greater power to shape behaviours that would other foodscapes individuals evolve in.

Eventually, inter-individual variability in normative influences on intended food choices have been highlighted, which would benefit from further investigation. For instance, in an experimental study, Croker et al. demonstrated that, although women rated the importance of norms on food choices more highly than men, intentions to eat fruit and vegetables were actually influenced by normative information only in men (p=0.011) (Croker, Whitaker et al. 2009).

Food purchase routines

Food acquisition is a regular activity, with individuals (usually) shopping weekly (White, Bunting et al. 2004; Gustafson, Christian et al. 2013), and increasingly eating out (Harnack, Jeffery et al. 2000; Orfanos, Naska et al. 2009). Over time, food acquisitions tend to become routines (Ilmonen 2001), with one (or a few) type(s) of outlet preferentially visited for main food purchases (White, Bunting et al. 2004). Experimental work on the condition under which food choices are made has shown that an increased number of alternatives is associated with individuals being more likely to guide their choice toward the same alternative repetitively (Anderson, Taylor et al. 1966). The authors concluded that as the number of choices increases, the decision becomes more difficult and uncomfortable for individuals. Repeating past choices may therefore be used as an unconscious mechanism to facilitate decisions in complex situations. Drawing from this findings, outlet patronage routines may be viewed as an unconscious way to ease the decision-making process in a context of food outlets abundance (Ilmonen 2001). These routines may additionally be consolidated by place attachment – i.e. "the emotional bond formed by an individual to a physical site due to the meaning given to the site through their interaction" (Milligan 1998). Place attachment is well illustrated by Cannuscio et al. who have shown that individuals who frequently visit a store they initially felt reluctant to, end up becoming attached to that place (Cannuscio, Weiss et al. 2010). Place attachment transforms non-cognitive routines into a genuine place commitment decreasing the perceived substitutability of other sites for the one in question (Milligan 1998). This may be especially true when that place fulfills essential needs like eating (Hull, Lam et al. 1994; Milligan 1998). Eventually, routines are further solidified through their intertwining with other life activities (e.g. working, collecting children at school, worshiping) that are similarly routinized (Flamm, Jemelin et al. 2008). Days thus become regularised by the repetitive visitation of 'usual places' (Flamm and Kaufmann 2006). Overall, routines witness how foodscape use is influenced by past use of the foodscape.

Some routinized food purchases may cohabitate with a more impulsive use of the foodscape. For instance, individuals may report frequent visitation of one outlet, complemented by occasional visitation of others. Furthermore, routines may break down in specific circumstances, enabling individuals to reassess available foodscape opportunities. For instance, new life events such as child birth or a change of home-place may push individuals to reconsider the options that may satisfy them (Flamm, Jemelin et al. 2008). These 'windows of opportunity' for change (Flamm, Jemelin et al. 2008; Gillespie and Johnson-Askew 2009) may enrich our understanding of what might push individuals to make the most of the healthy options offered by the foodscape. Yet, changes in the life course are largely overlooked by a research field standing behind essentially ahistoric conceptual positions on access.

Towards the need to differentiate access from exposure

Overall, we have identified two interconnected but distinctive ways by which the foodscape may influence dietary behaviours (see Figure 1). First, the characteristics of healthy and unhealthy outlets that individuals, endowed with certain preferences, means and constraints, may consider with attention (e.g. location, prices), render these outlets differentially *accessible*. However, people's limited ability to acquire and effectively utilise the information displayed in their environment led us to outline a second, less-conscious (and also less explored) set of foodscape influences. Foodscape *exposure* may stimulate with little deliberation biological interests for unhealthy food sources, unconsciously dictate which outlets are appropriate to use, and finally impact on the development of routinized outlets' visit. From that perspective, exposure should be distinguished from access, although both notions are often used interchangeably in the literature on foodscape. Failure to recognise this may lead to underestimate foodscape influences on dietary behaviours. For instance, an environment which offers access to a few healthy outlets, but which is also inundated with countless unhealthy outlets whose exposure to may push individuals to opt without much deliberation for these unhealthy alternatives, may be erroneously considered as health-promoting if the focus is only on access. We could just as well be wrong to conclude that an environment is health-promoting simply because individuals are exposed to high densities of healthy outlets, without looking at whether these outlets are actually accessible (i.e. affordable, convenient and acceptable). In sum, we argue that both exposure and access need to be looked at to conclude about the health-promoting or health-detrimental effect of foodscapes.

We have also highlighted inter- and intra-individual variabilities in the manner the foodscape may shape dietary behaviours. Over the time, individuals tend to alternatively rely on low and high involvement in decision-making (Beharrell and Denison 1995), leading to variable level of influence of foodscape exposure on individual behaviours. The situational factors that push them to variably engage in a more or less rational way with their environments would need further investigation. Moreover, individual attributes such as gender (Boone-Heinonen, Gordon-Larsen et al. 2011; Macdonald, Ellaway et al. 2011; Sharkey, Johnson et al. 2011), psychosocial traits (Paquet, Daniel et al. 2010), and socioeconomic characteristics (Boone-Heinonen, Gordon-Larsen et al. 2011), may further modify the relationship of exposure and access with dietary behaviours.

Implications for research

More evidence-based research is needed to identify the aspects of the foodscape that are practically and efficiently amenable to change via policy response. Practical guidance to improve our way of assessing potential access has been produced elsewhere (e.g. (Bhatnagar and Ratchford 2004; Lytle 2009; Chen and Kwan 2015)). We will therefore confine ourselves briefly to suggesting directions for future research that may enable better assessment of foodscape exposure.

- **Moving from a home-based to an activity-space approach when assessing the *configuration* of exposure**

The activity-space, or "subset of all locations within which an individual has direct contact as a result of his or her day-to-day activities" ((Golledge and Stimson 1997) p. 279) should be more widely used to delineate foodscape exposure (Sherman, Spencer et al. 2005; Flamm and Kaufmann 2006; Perchoux, Chaix et al. 2013). Alongside mobility surveys (Taylor, Young et al. 1988), technical tools such as GPS devices and web-based computer applications (e.g. (Chaix, Kestens et al. 2012)) can help track individual daily movements and behaviours across space (Matthews 2008).

- **Better assessing the *content* of exposure**

When questioning foodscape capacity to stimulate automatic interests for unhealthy options, looking at the density of unhealthy outlets within individuals' daily path may be valuable. Moreover, investigating the relationships between relative densities of healthy and unhealthy outlets and dietary behaviours may help question foodscape's normative influences, although qualitative studies in the field of environmental psychology would be complementarily needed to help progress in this regard. Eventually, testing individual-differences in the foodscape-diet relationship with regard to socio-demographic and psychosocial traits would be timely, as would refining our definitions of “healthy” and “unhealthy” outlets (Vernez Moudon, Drewnowski et al. 2013).

- **Make more use of natural experiments**

Exploiting the opportunities offered by “natural experiments”, such as openings/closures of certain types of outlets, and shifts in the type of outlets dominating a foodscape, may help build evidence of foodscape exposure influences on diet, and assist in the identification of effective interventions (Petticrew, Cummins et al. 2005). Overall, using more longitudinal designs would be timely.

CONCLUSION

The father of medicine Hippocrates, quoted with "Let food be your medicine”, introduced over two millennia ago the now well-argued idea that a balanced diet is essential to good health. So why do people continue to eat unhealthily when the consequences are so well-known (WHO 2008)? As brought to light by ecological approaches (Green, Poland et al. 2000; Story, Kaphingst et al. 2008) , it may partly be because eating is shaped by influences that are beyond the control and/or awareness of individuals. In westernised societies, the abundance of food sources may give the illusion of individual choice. Yet, we have shown peoples’ varying degree of autonomy when deciding how to use the foodscape. Beyond the practical questions of potential access, natural predispositions of individuals for low-level brain involvement open the way for a range of environmental influences on dietary behaviours. Yet, surprisingly, the involvement of national and international authorities has mainly relied (and still does) on education based programs rather than targeting modifications at the structural level of food trading. Since the foodscape is man-made, we may logically expect it to be easily re-shapeable (Eckert and Shetty 2011). Yet, in a context of globalisation and neo-liberal economic sovereignty (Chopra, Galbraith et al. 2002), the dominance of consumerism above health (Caraher and Coveney 2004; Moodie, Stuckler et al. 2013), and the control of food distribution by dominant food institutions (Welsh and MacRae 1998) may restrict such reshaping. A lack of clear guidance regarding in what way and to what extent the foodscape should be altered to observe significant and sustainable shifts towards healthier dietary behaviours acts a further barrier that public health research must surpass. Providing stronger evidence on how and how much the foodscape constrains individuals from visiting healthy and less-healthy outlets would be timely to win political support for legislation and intervention, and to regain some degree of control over food production and distribution from the dominant food and retailing institutions (Welsh and MacRae 1998).

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CHAPTER 4. TWO EMPIRICAL CASE STUDIES: RELATIVE EXPOSURE TO HEALTHY AND UNHEALTHY OUTLETS AND FRUIT AND VEGETABLE INTAKE AMONG WOMEN AND MEN IN URBAN CANADA

4.1. Rationale

Low fruit and vegetable consumption is a risk factor associated with obesity, coronary heart disease, stroke, type 2 diabetes, diverticulosis, hypertension, and certain types of cancer (Aldoori, Giovannucci et al. 1994; Steinmetz and Potter 1996; Ness and Powles 1997; Aldoori, Giovannucci et al. 1998; McCrory, Fuss et al. 1999; Sacks, Moore et al. 1999; Bes-Rastrollo, Martínez-González et al. 2006; Research 2007). The nutritional quality of most Canadian adults' diet is far from both the Canadian Food Guide and international recommendations. Half of all adults in Canada do not consume the recommended daily servings of fruits and vegetables (Garriguet 2004; Garriguet 2007). This is especially true for Canadian men, who tend to report lower consumption of fruit and vegetables than Canadian women (Pérez 2002; Garriguet 2004; Langsetmo, Poliquin et al. 2010; StatCan 2013). These gender-differences are consistent with worldwide figures (Drewnowski and Greenwood 1983; Thompson, Margetts et al. 1999; Wardle, Parmenter et al. 2000; Beardsworth, Bryman et al. 2002; Baker and Wardle 2003; Wardle, Haase et al. 2004; White, Bunting et al. 2004; Prattala, Paalanen et al. 2007), and the large amount of research more broadly highlighting less-healthy dietary behaviours among men than women (Whitfield, Weidner et al. 2002; Arganini, Turrini et al. 2012). A major contributor to the rising global burden of chronic diseases, low fruit and vegetable consumption is also considered a *modifiable* risk factor (WHO/FAO 2003).

So far, the involvement of Canadian authorities to tackle low fruit and vegetable consumption – and more globally unhealthy diets – among adults has resulted more in education based programs than in alteration of the structural level of food trading. Beyond the standardisation of nutritional labelling, most efforts have consisted in providing dietary advice and information on the nutritional value of food, in particular through the development and distribution of the Canadian Food Guide (Canada 2007;

Katamay, Esslinger et al. 2007). Hence, governmental action for improving dietary behaviours have mostly consisted in empowering individuals through education, rather than modifying the environmental conditions they live in (Hedley 2006).

Yet, Canada has long recognised environmental influences on health behaviours. The *Lalonde report* (1974), named after Mark Lalonde, Canadian Minister of National Health and Welfare (1972-1977), and formally titled *A new perspective on the health of Canadians*, is considered the first modern government document in the Western world that acknowledges changing the environment as a way to improve population health (Hancock 1985). In 1986, the *Ottawa Charter for Health Promotion*, internationally recognised as the founding pillar of health promotion, also put a large emphasis on the need for creating health supportive environments in order to sustainably improve populations' health-related behaviours (WHO 1986). The move away from behavioural change perspectives among at-risk individuals towards recognition of environmental determinants of health behaviours is however weak regarding food policies.

Since Canada's inception, agricultural production has been the primary driver of food-related policy, and the food system remains mainly designed to encourage people to consume for firm profitability (MacRae 2011). Some have argued that governments' reluctance to regulate or restrict consumer food choice is an impediment to creating a national and integrated food policy that would extend beyond the traditional food safety, food marketing and fraud prevention framework (Hedley 2006; MacRae 2011). The Agricultural Policy Framework (APF) agreed between federal and provincial governments in 2003 and renewed in 2013, in order to link food safety and quality, environment, business risk management, renewal, innovation and trade, is the most historically evolved form of joined up food policy in Canada (Hedley 2006). Nonetheless, these agreements are weak on addressing health, social, and cultural issues beyond those related to food safety, and do not enter the realm of foodscape alteration (Hedley 2006). At a local scale, actions have laudably been undertaken to reshape the environment in favor of facilitated access to nutritious foodstuffs, like fruit and vegetable. For instance, Food Share (http://www.foodshare.net/), a non-profit organization in Toronto, has been working since 1985 with communities and schools to help secure their access to fresh, nutritious, culturally appropriate, and affordable food. This has been made possible through developing empowering tools and scalable solutions with and for communities, in term of production, distribution and consumption. But overall, Canada, like many countries of the industrial world, faces a lack of coherent and integrated national food policy that would address dietary behaviours and the forces that shape them (Hedley 2006). As a consequence, food remains primarily something to be bought and sold, rather than a biological and socio-cultural necessity (MacRae 2011). Moreover, current policies do not address gender-differences in dietary behaviours.

The lack of a clear understanding of the mechanisms by which the foodscape shapes dietary behaviours – and may do it differentially among certain groups of population - has been pointed out as a limitation for effectively modifying the structural level of food trading (Hedley 2006). In the previous chapter (Chapter 3 – Conceptual framework), we have proposed a novel conceptualisation of foodscape influences on dietary behaviours. We have especially highlighted the potential for relative measures of exposure to grasp what we meant to be the "normative dimension" of the foodscape. In Canada, there is some evidence of association between relative measures of foodscape exposure and diet. Mercille et al.'s cross-sectional study among seniors living in Montréal (Mercille, Richard et al. 2012) has shown that the proportion of fast-food outlets relative to all restaurants around home was inversely associated with 'prudent' diet scores - 'prudent' diet reflecting high consumption of fruit and vegetables (β=-0.105; $P<0.05$). The proportion of stores selling healthy foods relative to all stores was further inversely associated with lower 'western' diet scores ('western' diet reflecting low consumption of fruit and vegetables) (β=-0.124; $P<0.01$). In a similar vein, Van Hulst et al. reported that children from Quebec attending a school in a neighbourhood with a Retail Food Environment Index higher than 2.5 (RFEI measured as the ratio of the number of fast-food restaurants and convenience stores to supermarkets and specialty food stores) were eating up to a half a serving less of fruit and vegetables (β=-0.40, 95% CI: -0.81, 0.005 for residential neighbourhood and β=-0.50, 95% CI: -0.91, -0.09 for school neighbourhood) compared to children attending a school in a neighbourhood with a RFEI lower than 2.5 (Van Hulst, Barnett et al. 2012). However, these findings cannot be inferred to Canadian adults, nor do they allow to distinguish possible differential effects of the foodscape on men and women.

There is some evidence that normative influences on intended food choices (Croker, Whitaker et al. 2009) and volume of intake (Wansink and Cheney 2005; Hermans, Herman et al. 2010) may be stronger for men than women. In an experimental study, Croker et al. demonstrated that, although women rated the importance of social norms on food choices more highly than men, intentions to eat fruit and vegetables were actually influenced by normative information only in men (p=0.011). These findings suggest that what people believe motivates their choices may be different from what actually motivates their choice (Nolan, Schultz et al. 2008). But most importantly, these findings suggest that men and women may be differentially influenced by the normative dimension of their environment. In the current context of westernised cities dominated by unhealthy outlets, if men are assumed to be more responsive than women to the normative dimension of the foodscape, it may not be surprising that they eat less healthfully that their feminine counterparts in environments that do not encourage healthful eating.

However, factors behind gender-differences in dietary behaviours have often been assumed to relate to taste preferences/aversions (Nordin, Broman et al. 2004; Lucan, Barg et al. 2010), nutritional knowledge (Turrell 1997; Nayga 2000), health concern (Drewnowski and Greenwood 1983; Nayga 1997; Wardle, Haase et al. 2004), and dieting status (Wardle, Haase et al. 2004). Relatively, the extent to which men and women may be differentially influenced by their foodscape has been given less attention. To our knowledge, only two US studies have explored gender differences in the foodscape-diet relationship. Both found men's diet to be more strongly associated to the local foodscape than women's diet (Macdonald, Ellaway et al. 2011; Sharkey, Johnson et al. 2011). Macdonald et al. observed that men, but not women, were significantly less likely to eat five portions of fruit and vegetables daily if they lived within 1000 m of a supermarket ($p < 0.01$) (Macdonald, Ellaway et al. 2011). By way of explanation of the counterintuitive direction of this relationship, authors suggested that proximity to a supermarket may be a marker of proximity to a range of destinations competitively selling energy dense foods. This argument makes sense in view of our conceptual proposal (Chapter 3) and the need for considering the competitive presence of less-healthy alternatives that we have highlighted. Sharkey et al. found that shorter distance to the nearest fast-food source and increased density of fast-food source around home were associated with more frequent consumption of fast-food meals among men (Sharkey, Johnson et al. 2011). For women, however, it appeared to be the exact opposite, with greater distance to the nearest fast-food source and decreased density of fast-food sources around home being associated with more frequent consumption of fast-food meals.

In light of the above, it appears necessary to explore associations between relative measures of exposure to the foodscape and fruit and vegetable intakes among Canadian adults, and to investigate potential gender-differences. Moreover, studies using relative measures to look at the foodscape-diet relationship have mostly focused on the foodscape around home, that is, residential exposure. The residential neighborhood is a meaningful geographical anchor point and a privileged area for implementing public health policies (Diez Roux 2001), and hence deserves particular attention. However, Canadian adults are mobile and tend to travel beyond their residential neighborhood (Kestens, Lebel et al. 2010; Morency, Paez et al. 2011). Because foodscape exposures around home and away from home tend to be different (Kestens, Lebel et al. 2010; Burgoine and Monsivais 2013), non-residential foodscape exposure also deserves exploration.

To address these gaps, the following empirical research explores the relationship between fruit and vegetable intakes and relative exposures to healthy and unhealthy outlets, both around home and in the non-residential environment, among men and women, in urban Canada.

4.2. Specific objectives and research hypotheses

Specific objectives and hypotheses outlined below correspond to those of Articles 2 and 3 presented in the following chapter.

Article 2 aims to explore the relationship between foodscape exposure around home and fruit and vegetable intake, among adults living in the five largest Canadian metropolitan areas (Toronto, Montreal, Vancouver, Ottawa and Calgary). More specifically, we:

1/ explore whether the relative density of healthy and unhealthy food outlets (i.e. relative measure of foodscape exposure) is a better correlate of fruit and vegetable intake than densities of healthy and unhealthy food outlets taken separately (i.e. absolute measures of foodscape exposure);

2/ test whether the relationship between relative measures of foodscape exposure and fruit and vegetables intake is modified by gender.

It is hypothesised that:

1/ Relative measures of foodscape exposure are overall better correlates of fruit and vegetable intake than absolute measures;

2/ The relationship between relative measures of foodscape exposure and fruit and vegetable intake is modified by gender, with a stronger correlate for men than for women.

Article 3 aims to explore, separately for men and women living in the Montreal Census Metropolitan Area (MCMA), the relationship between the foodscape experienced in the subset of out-of-home visited places (non-residential exposure) and fruit and vegetable intake. More specifically, we:

1/ test whether densities of food outlets experienced around home (residential exposure) differ from those experienced in the subset of out-of-home visited places (non-residential exposure), for men and women separately.

2/ assess the relationship between non-residential exposures and fruit and vegetables intake, for both men and women.

It is hypothesised that:

1/ estimates of residential and non-residential exposures to the foodscape are significantly different, for both men and women.

2/ non-residential exposure is associated with the quality of diet as follows: the more the foodscape is dominated by healthy outlets, the higher the consumption of fruit and vegetables. We further assume that the correlate will be stronger for men than for women.

4.3. Methods

4.3.1. Study design and population

This research project used a cross-sectional design. It targeted non-institutionalized Canadian men and women aged 18 and over, and living in the five largest Census Metropolitan Areas (CMAs) in Canada — Toronto, Montreal, Vancouver, Ottawa, and Calgary (Article 2), or in the Montreal CMA only (Article 3).

No single database existed that gathered all the information needed to answer our research questions. Consequently, the research project capitalised on three databases and used linkage procedures relying on both spatial analysis and inferences in order to assess residential and non-residential foodscape exposure and eventually model fruit and vegetable intakes (FVI). These three secondary databases are: the Canadian Community Health Survey (CCHS) from Statistics Canada, the EPOI Canadian retail stores datasets distributed by DMTI Spatial®, and the 2008 Origin-Destination survey which is a joint realisation of seven partners: the Agence Métropolitaine de Transport, the Société de Transport de Montréal, the Réseau de Transport de Longueuil, the Société de Transport de Laval, the Association Québécoise du Transport Inter-municipal et Municipal, the Ministère des Transports du Québec, and the Ministère des Affaires Municipales, des Régions et de l'Occupation du Territoire.

a) The Canadian Community Health Survey (CCHS)

The CCHS is a repeated cross-sectional survey that has been collecting information related to sociodemographic status, health status, and health determinants (including fruit and vegetable intakes) for the Canadian population since 2000. Data collection occurred every two years prior 2007, then every year. The collection relies upon a sample of about 65,000 respondents every year (about 130 000 respondents for collection occurring every two years) and is designed to provide reliable estimates to health region level. The CCHS questionnaire is administered by phone to volunteer respondents using computer-assisted interviewing.

The pooled 2007-2010 cycles of CCHS were used to assess FVI (our outcome) and provide individual- and household-level modifying and control variables included in our models for both articles 2 and 3.

b) The 2008 Regional Origin-Destination (OD) survey

The 2008 Origin-Destination (OD) is a computer-assisted phone-interview mobility survey, conducted during autumn 2008 on 156 720 individuals living in the Montréal Census Metropolitan Area (i.e. 4.1% of the MCMA population). Surveyed households were selected via random digit dialling in each of the 108 geographical strata dividing the MCMA. Variables include household type and activity destinations (georeferenced locations) for all household members aged four and above for the weekday prior to the phone interview.

In Article 3, the 2008 OD survey was used to describe and model the non-residential foodscape exposure of inhabitants of the MCMA.

c) The Enhanced Points of Interest (EPOI) dataset

The 2010 Enhanced Points of Interest (EPOI) file, distributed by DMTI Spatial®, is a commercial list of businesses across Canada. For each listed food business (retail food stores and restaurants), the EPOI file provides the name, geographic coordinates, and between one and six Standard Industrial Classification (SIC) codes based on the economic activities declared (OSHA 2008). The Standard Industrial Classification (SIC) is a system for classifying businesses by a four-digit code, ranging from 0111 to 9721. The first digit indicates the division, the first two digits the major group, and the first three digits the industry group. To look at a particular example, SIC code 5431 *Fruit and Vegetable Markets* belongs to industry group 543 *Fruit and Vegetable Markets*, which is part of major group 54 *Food Stores*, which belongs to the division *Retail Trade*.

The dataset, validated in 2010 in Montreal using ground-truthing, has shown a good capacity to assess local densities of outlets. Representativity of the dataset, that is, concordance between outlets present on the EPOI list and outlets observed on the field was 77.7% when relaxing on business names, small imprecisions in location (i.e. within the same census tract), and when compensating false negatives with false positives within the same outlet category and census tract (Clary and Kestens 2013) (see Appendix I for more details).

In articles 2 and 3, the 2010 EPOI database was used to derive local densities of food stores (absolute and relative densities) and assess foodscape exposures both around home and in the non-residential environment.

d) Databases linkage: overview

In order to assess residential foodscape exposures of CCHS-participants, kernel densities of food outlets were derived from the 2010 EPOI database, then extracted at CCHS-participant's 6-digit residential postal code, and eventually used to model FVI.

Assessment of non-residential exposure for CCHS-participants, needed in the article 3 but not directly available due to the absence of data on CCHS-participants' mobility, added up a further step. For OD-participants, density values of food outlets were also derived from the 2010 EPOI database, and then extracted at the geographic coordinate of all visited places excluding home. This non-residential exposure was modeled among OD-participants, using Multiple Imputation techniques with a wide range of individual, household and environmental variables, and then inferred to CCHS-participants. *Estimates* of non-residential foodscape exposure of CCHS-participants were eventually used to model their FVI (the procedure is detailed below).

4.3.2. Variables

Outcome - Fruit and vegetable intake (FVI) was computed by adding up consumption of the four following items collected in the CCHS Food Frequency Questionnaire (FFQ): the number of portions of “fruits (excluding fruit juices)”, “green salad”, “carrots”, and “other vegetables (excluding carrots and green salad)”. This excluded potatoes in order to be consistent with international recommendations for the intake of fruit and vegetables (FAO/WHO 2004). Respondents were free to report the number of portions they ate either per month, per week or per day. All data were transformed into daily consumptions and summed up to obtain a FVI variable.

Foodscape exposure - Using a SIC code and name-based assignment method of categorization, ten categories of food outlets – supermarkets, grocery stores, convenience stores, bakeries, fruit and vegetable stores (FVS), specialty stores (e.g. butcher), natural food stores (NFS), fast-food restaurants (FFR), full-service restaurants (FSR) and cafés – were extracted from the EPOI dataset (Clary and Kestens 2013) (see Appendix I for more details). Each outlet category was further classified as either a “healthy” or an “unhealthy” food source. The term “healthy” restrictively referred to outlets that allow for complete meals with fruit and vegetable options, and included supermarkets, FVS, NFS, and grocery stores. Inversely, outlets allowing for complete meals but offering few or no fruit and vegetable options were termed “unhealthy”. They encompassed convenience stores and FFR. Bakeries and specialty stores were excluded from analyses as they do not allow for complete meals. FSR and cafés were also trimmed, as the assignment method used to categorize those outlets was insensitive regarding how much fruit and vegetable options they offered.

To derive local densities of food outlets, Kernel Density Estimations (KDEs) were computed in Crimestat (Levine 2005) for each of the six retained food outlets categories and for each Census Metropolitan Area (CMA). KDE is an interpolation technique that transforms discrete spatial data into continuous density estimations based on a kernel of particular bandwidth and symmetrical density function (Silverman 1986). The bandwidth can be defined so that the distance from the observation point is either constant (*fixed* kernel density) or varies to maintain the number of observations under the curve constant (*adaptive* kernel density). The surface value is highest at the location of the observation point (i.e. food outlet location) and diminishes with increasing distance from this point, reaching its lowest value (e.g. zero for a quartic kernel) at the search radius (bandwidth) distance. The output is a raster file, with density estimates provided at each raster cell centre by adding the values of all kernel surfaces. KDEs are frequently used in geography to evaluate the local density of discrete data (Carlos, Shi et al. 2010) and have been used previously to assess foodscape exposure (e.g. (Moore, Diez Roux et al. 2008; Moore, Diez Roux et al. 2008; Kestens, Lebel et al. 2012; Lebel, Kestens et al. 2012; Van Hulst, Barnett et al. 2012)). For each type of food outlet and CMA, KDEs were computed for raster cells of a 30 meter size, with a quartic function and an adaptive bandwidth using 5% of the nearest observations.

The use of the adaptive bandwidth method has been motivated by two elements. First, adaptive KDEs preserve consistent statistical precision across the study area, mitigating the impact of small numbers. In sum, the power to detect an effect in one place is the same as in any other place. Second, the use of an adaptive bandwidth further relies on the assumption that the distance of influence for a given outlet may be inversely related to the number of stores available in the surroundings. Stores located in low density areas may have a larger attractiveness area than stores located in high density areas, where competition prevents traveling long distances. This view is supported by a recent study from Kerr *et al.*, reporting that the mean distance traveled to shop at grocery stores and fast-food restaurants (densely distributed) was considerably shorter than to shop at superstores (less densely distributed) (Kerr, Frank et al. 2012). Underlying the use of an adaptive KDE is therefore the idea that what individual are exposed to should vary as a function of the distribution of food resources around the anchor point (home, or non-home place visited). The 5% threshold was chosen in accordance with previous studies (Kestens, Lebel et al. 2012; Lebel, Kestens et al. 2012), and because visual evaluation of kernel densities pointed towards possible over- and under-smoothing with larger (i.e. 10% of neighbours) or smaller (1%) bandwidths respectively. Moreover, sensitivity analyses carried out on a sample of East-London residents bring further justification for the use of bandwidths with the range 5% to 7% neighbors (see Appendix II – Clary et al. *Submitted*). The boundaries between study (CMAs) and non-study (out of CMAs) areas are likely to be crossed as part of daily activities including the use of food outlets. In order to mitigate edge effect, KDEs were computed for each CMA including a buffer zone of 30 kilometers.

For CCHS-participants density values for each outlet type were then extracted at the centroid of the 6-digit postal code of residence, using ArcGIS v10.1. For OD-participants, density values for each outlet type were extracted at the geographic coordinates of each visited place (including home). The densities of supermarkets, FVS, FFR, and the sums of densities of all healthy and all unhealthy food outlets were used as absolute measures in the analyses. Supermarkets and FFR have been retained because most studies traditionally point to those two outlet types as good and limited sources of fruit and vegetables, respectively (Charreire, Casey et al. 2010). FVS was also retained because this outlet type is relevant to our outcome. Eventually, all healthy and all unhealthy outlets were retained, as our conceptual framework suggests the importance to consider more broadly all potential outlet alternatives. A relative measure was computed, measured as the percentage of healthy outlets — i.e. summed density of healthy stores divided by the sum of densities of all considered outlets.

For both OD- and CCHS-participants, residential exposures were simply computed as the score of exposure at home.

For OD-participants, non-residential exposures for each measure of density were computed as the mean score of exposure at all visited places excluding home. Individuals visiting a same location were attributed the same level of exposure, regardless individuals' time spent at that place.

For CCHS-participants, non-residential exposures could not be assessed directly, since CCHS surveys did not provide any information about individuals' mobility. Previous literature has shown that foodscape exposure could be modelled using individual, household and environmental variables (Kestens, Lebel et al. 2010; Kestens, Lebel et al. 2012; Lebel, Kestens et al. 2012). Both OD- and CCHS survey participants were drawn from the same original population (Montreal Census Metropolitan Area). They share similar characteristics (Table 1). Consequently, data available for OD-participants was used to impute missing information on non-residential exposure for CCHS-participants. Multiple Imputation (MI) was used under the normality assumption to impute, separately for men and women, estimates of non-residential exposure from a wide range of individual, household and environmental variables characterising the place of residence. MI is a Monte Carlo technique. It constructs several completed data-sets from the original incomplete data by replacing the missing values in each data set by random draws from the conditional distribution of the missing data (given observed data). Each of the simulated complete datasets is then analyzed separately by standard methods, and the results are combined to produce estimates and confidence intervals that incorporate missing-data uncertainty - i.e. that account for the differences within (variation due to sampling) and between (variation due to imputation) data sets. OD- and CCHS-databases were consequently merged and then stratified by sex. MI were performed with 20 iterations, since the percentage of missing values for non-residential exposure variables (i.e. the percentage of CCHS-participants) was about 20% after both databases were merged (Allison 2012). All individuals, household and environmental variables common to both dataset were used as predictors for the missing information. This included individual (age, sex, working status) and household (household structure) variables, as well as a long list of environmental variables referring to the sociodemographic (proportion of single parent families, Proportion of people age 65 and over, Proportion of single persons in the population 15 years of age and over, Proportion of individuals speaking English at home, Proportion of people having moved last year, Proportion of immigrants, Proportion of people without certificate, diploma or degree in the population 25 years of age and over), socioeconomic (e.g. Mean household income, Proportion of active female mass transit in the population 15 years of age and over, Material deprivation, based on the Pampalon Deprivation Index, Social deprivation, based on the Pampalon Deprivation Index) and physical (e.g. Proportion of buildings built before 1946, Proportion of dwellings needing major repair, Connectivity_3, as the number of three-ways intersections per buffer area, Connectivity, as the number of four-ways intersections per buffer area, Land use mix, as the entropy index of land use mix, Commercial density) characteristics of the residential neighborhood. Characteristics of the residential environment, provided by the 2006 census at census tract (CT) or dissemination area (DA) scale, were extracted in an 800-meter road-network buffer around residential 6 digit-postcodes. Scores were weighted proportionally to the surface area of the overlap between the buffer zone and CT/DA. Absolute measures, whose distributions were skewed, were transformed into logarithms in order to approximate normality for imputation, and transformed back to their original scale after imputation.

Demographic and socio-economic characteristics - Variables retained as covariates were the following: gender (female, male), age ([18-29]-[30-44]-[45-64][65 and more]), educational attainment (less than secondary grade, secondary degree, post-secondary grade, post-secondary degree), ethnic origin (White, Asian, Black, other), employment status (full-time worker, part-time worker, student, retired), marital status (single, couple, couple with children, single parent, other), household size adapted income before tax deductions (i.e. income categories adjusted for the number of individuals per household and categorized into quartiles: low, mid-low, mid-high, high), and both material and social neighborhood deprivations. CMA of residence (Toronto, Montreal, Vancouver, Ottawa, Calgary) was also included as covariate in the models of Article 2.

4.3.3. Analytical procedure

Analysis related to Article 2 **-** First, linear regression models were built to estimate the associations between absolute (supermarkets, FVS, FFR, all healthy and all unhealthy) and relative (percentage of healthy stores) densities of outlets and FVI in CCHS participants, using SPSS v.20. Aikake Information Criteria (AIC) and Variance Inflation Factors (VIF) were reported to assess model performance and identify potential multicollinearity issues, respectively. All regression models were adjusted for gender, age, educational level, marital status, ethnic origin, household income, CMA of residence, and neighborhood material and social deprivations.

Second, interactive effects of each measure of exposure with gender and CMAs were tested, with “women” and “Montreal” chosen as reference groups. When interactions were significant, the population sample was stratified in consequence, and estimates of the association between exposure measures and FVI were re-assessed in each subsample.

Spatial autocorrelation analyses of standardized residuals were performed with GeoDa v.0.9.9.8, using Moran's Index. Due to data clustering linked to the treatment of distinct CMAs that were distant from each other, spatial autocorrelation analyses were performed separately for each CMA. Spatial weights were row-standardized (i.e. each neighbor weight for an observation was divided by the sum of all neighbor weights for that observation) and Euclidean inverse distance-based, with the bandwidth chosen to ensure that each location had at least one neighbor.

Because original CCHS weights were aimed to be applied to the complete sample, they were not adapted to our subsample. All analyses were therefore performed without weighting.

Analysis related to Article 3 - First, analysis of variance (ANOVA) was performed to compare residential and non-residential foodscape exposures for OD-participants.

Second, multivariate linear regressions were used on CCHS-participants to test, separately for men and women, the associations between FVI and each non-residential measure of exposure. All regression models were adjusted for age, educational level, marital status, ethnic origin, income, neighborhood material and social deprivations, and residential exposure. All statistical analyses were performed in SPSS, v20.0.

CHAPTER 5. RESULTS

ARTICLE 2

Title : Should we use absolute or relative measures when assessing foodscape exposure in relation to fruit and vegetable intake? Evidence from a wide-scale Canadian study

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ABSTRACT

Objective: This paper explores which of absolute (i.e. densities of “healthy” and “unhealthy” food outlets taken separately) or relative (i.e. the percentage of “healthy” outlets) measures of foodscape exposure better predicts fruit and vegetable intake (FVI), and whether those associations are modified by gender and city in Canada.

Methods: Self-reported FVI from participants of four cycles (2007-2010) of the repeated cross-sectional Canadian Community Health Survey living in the five largest metropolitan areas of Canada (n=49,403) were analysed. Absolute and relative measures of foodscape exposure were computed at participants’ residential postal codes. Linear regression models, both in the whole sample and in gender- and city-stratified samples, were used to explore the associations between exposure measures and FVI.

Results: The percentage of healthy outlets was strongly associated with FVI among men both in Toronto/Montreal (β=0.012; *P*<0.001), and in Calgary/Ottawa/Vancouver (β=0.008; *P*<0.001), but not among women. Observed associations of absolute measures with FVI were either weak or faced multicollinearity issues. Overall, models with the relative measure showed the best fit.

Conclusions: Relative measures should be more widely used when assessing foodscape influences on diet. The absence of a single effect of the foodscape on diet positions sub-group analysis as a promising avenue for research.

INTRODUCTION

Over the last decade, a growing body of research has explored the potential influences of the *foodscape* – defined as "the multiplicity of sites where food is displayed for purchase and where it may also be consumed" (Winson 2004) - on diet (Caspi, Sorensen et al. 2012). Conflicting findings (Caspi, Sorensen et al. 2012) have, however, led to question the traditional way of modeling the foodscape-diet relationship (Lytle 2009).

Foodscape exposure has mostly been assessed using *absolute* measures of access to *either* "healthy" food outlets – overlooking "unhealthy" sources, *or* "unhealthy" outlets – ignoring "healthy" ones (Charreire, Casey et al. 2010). Yet, since individuals tend to get exposed simultaneously to "healthy" and "unhealthy" food sources (Kestens and Daniel 2010), "unhealthy" outlets are likely to act as a proxy measure of "healthy" stores (and inversely) (Leal, Bean et al. 2012). A few studies (e.g. (Morland, Wing et al. 2002)) did control for the overall outlet density in an attempt to address this model misspecification. However, precisely because of high spatial correlation between outlet categories, problems of multicollinearity are likely to be introduced. Combining two collinear variables into an index has been proposed as a valuable method (York 2012). From that perspective, *relative* exposure measures, such as the percentage of food outlets considered "healthy" would be more appropriate. Only a few studies have compared relative to absolute measures, though (Mason, Bentley et al. 2013; Zenk, Powell et al. 2014). Furthermore, little is known about the consistency of associations between diet and those relative measures across populations and space. Yet, territorial variations in the foodscape-diet relationship within homogeneous groups of individuals have been highlighted (Fraser, Clarke et al. 2012), whilst non-uniform responses from individuals who share the same environment have been observed (Entwisle 2007; Thompson, Cummins et al. 2013). As an example, gender differences have been pointed out (Macdonald, Ellaway et al. 2011; Sharkey, Johnson et al. 2011).

Drawing on those limitations, the present paper aimed to explore whether relative measures of foodscape exposure are overall better correlates of fruit and vegetable intake (FVI) than absolute measures. Furthermore, the consistency of the relationship between those exposure measures and FVI is tested by gender and city in Canada.

METHODS

Data sources

Individual data was drawn from the Canadian Community Health Survey (CCHS) (Beland 2002), a repeated cross-sectional survey led by Statistics Canada and representative of the non-institutionalised Canadian population aged 12 and above. Initiated in 2000, the CCHS collects information related to socio-demographics, health outcomes, and health determinants, in a sample of approximately 65,000 Canadian each year. Four CCHS cycles (2007 to 2010) were combined for the present study. Adults 18 years and over living in the five largest Census Metropolitan Areas (CMAs) in Canada – Toronto, Montreal, Vancouver, Ottawa, and Calgary - were considered for inclusion in the analyses.

Foodscape data was obtained from the 2010 DMTI Spatial® EPOI (Enhanced Points of Interest) file, a commercial dataset of businesses across Canada. For each listed food business, the EPOI file provides the name, geographic coordinates, and between one and six Standard Industrial Classification (SIC) codes based on the economic activities declared (Administration 2008). Using a SIC code- and name-based assignment method of categorization, ten categories of food outlets - supermarkets, grocery stores, convenience stores, bakeries, fruit and vegetable stores (FVS), specialty stores (e.g. butcher), natural food stores (NFS), fast-food restaurants (FFR), full-service restaurants

(FSR) and cafés - were extracted from the EPOI dataset. (See (Clary and Kestens 2013) for more details). The dataset, validated in 2010 using ground-truthing, has shown a good capacity to assess local densities of outlets. Representativity of the dataset, that is, concordance between outlets present on the EPOI list and outlets observed on the field was 77.7% when relaxing on business names, small imprecisions in location (i.e. within the same census tract), and when compensating false negatives with false positives within the same outlet category and census tract (See (Clary and Kestens 2013) for more details).

Each outlet category was further classified as a “healthy” or an “unhealthy” food source. The term “healthy” restrictively referred to “outlets that allow for complete meals with fruit and vegetable options”, and included supermarkets, FVS, NFS, and grocery stores. Inversely, “outlets allowing for complete meals but offering few or no fruit and vegetable options” were termed “unhealthy”. They encompassed convenience stores and FFR. Bakeries and specialty stores were excluded from analyses as they do not allow for complete meals. FSR and cafés were also trimmed, as the assignment method used to categorize those outlets was insensitive regarding how much fruit and vegetable options they offer.

Measures

Dependent variable

Fruit and vegetable intake (FVI) was computed by adding up consumption of the four following items collected in the CCHS Food Frequency Questionnaire (FFQ): the number of portions of “fruits (excluding fruit juices)”, “green salad”, “carrots”, and “other vegetables (excluding carrots, potatoes, and green salad)”. Respondents were free to report the number of portions they ate either per month, per week or per day. All data were transformed into daily consumptions and summed up to obtain a FVI variable.

Foodscape exposure around home

For each food outlet category, a continuous density surface was computed in Crimestat v.3.3 using a quartic kernel with an adaptive search radius distance - or bandwidth (Carlos, Shi et al. 2010) - including 5% of the closest neighbors (Kestens, Lebel et al. 2012; Lebel, Kestens et al. 2012). Measures of density for each outlet category were computed and linked to each participant's 6-digit postal code using ArcGIS v10.1. The densities of supermarkets, FVS and FFR, and the sum of densities of all healthy and all unhealthy food outlets were used as absolute measures in the analyses. A relative measure was computed, measured as the percentage of healthy outlets – i.e. summed density of healthy stores divided by the sum of densities of all considered outlets.

Covariates

Gender, age ([18-29], [30-44], [45-64], [65 and over]), educational level (less than secondary grade, secondary degree, post-secondary grade, post-secondary degree), ethnic origin (White, Asian, Black, other), marital status (single, couple, couple with children, single parent, other), household size adjusted income (low, mid-low, mid-high, high), CMA of residence, and both material and social neighborhood deprivation were included in the models. Household size adjusted income was computed using both annual household income (12 categories) and the number of household members (three categories). The 2006 material and social dimension of the Pampalon deprivation Index (Pampalon, Hamel et al. 2009) available at the dissemination area level were extracted at the 6-digit postal code level to provide neighborhood material deprivation and neighborhood social deprivation variables.

To avoid deleting the 12 386 participants (23.59%) who had missing data on relevant variables (Table 1), we performed Multiple Imputation then Deletion (MID) (Von Hippel

2007),using SPSS v.20. In short, all observations and variables were used for multiple imputation but, following imputation, cases with imputed FVI values were excluded from the analysis.

Because the sample encompassed four waves of the CCHS survey, temporal variations might have been expected. Dummy variables for each survey cycle were included in preliminary analyses, but excluded from models since they were not significant.

Statistical analysis

First, six linear regression models were built to estimate the associations between each of the six exposure measures and FVI in the whole population sample, using SPSS v.20. All regression models were adjusted for gender, age, educational level, marital status, ethnic origin, income, CMA of residence, and neighborhood material and social deprivations.

Second, the interactive effects of each of the six foodscape exposure measures with gender and CMAs were tested, with “women” and “Montreal” chosen as reference groups. When interactions were significant, the population sample was stratified in consequence, and estimates of the association between exposure measures and FVI were re-assessed in each subsample.

Spatial autocorrelation analyses of standardized residuals were performed with GeoDa v.0.9.9.8, using Moran’s Index. Due to data clustering linked to the treatment of distinct CMAs that were distant from each other, spatial autocorrelation analyses were performed separately for each CMA. Spatial weights were row-standardised (i.e. each neighbor weight for an observation was divided by the sum of all neighbor weights for that observation) and Euclidean inverse distance-based, with the bandwidth chosen to ensure that each location had at least one neighbor.

Because original CCHS weights were aimed to be applied to the complete sample, they were not adapted to our subsample. All analyses were therefore performed without weighting.

RESULTS

Out of the 52,510 participants aged 18 or more and living in the five CMAs, 3,107 participants had a missing FVI and were deleted. Our final sample encompassed 49,403 individuals.

Descriptive analyses

The average FVI of participants was 3.98 portions per day (Table 1). Women were more likely to eat fruit and vegetables than men (*P*<0.001). FVI also varied by CMA (*P*<0.001), with Montreal having the highest (4.17 portions/day) and Toronto the lowest (3.86 portions/day) FVI.

Table 1 Socio-demographic characteristics and dietary intakes of CCHS participants, Canada, 2007-2010

	Total (N=49,403)	
	n	**%**
Gender		
Women	27241	*55.1*
Men	22162	*44.9*
Age group		
[18-29]	8610	*17.4*
[30-44]	13826	*28.0*
[45-64]	16429	*33.3*

[65+]	10538	*21.3*
Ethnic origin		
White	36233	*73.3*
Asian	7385	*14.9*
Black	1615	*3.3*
Others	2057	*4.2*
Missing	*2113*	*4.3*
Marital status		
Single	14750	*29.9*
Couple	13359	*27.0*
Couple with children	13418	*27.2*
Single parent	3414	*6.9*
Other	4297	*8.7*
Missing	*165*	*0.3*
Education level		
Less than secondary	6211	*12.6*
Secondary graduate	7531	*15.2*
Other post-secondary grade	3804	*7.7*
Post-secondary graduate	30440	*61.6*
Missing	*1417*	*2.9*
Household size adjusted income		
Low	2946	*6.0*
Mid-low	6300	*12.8*
Mid-high	12344	*25.0*
High	19532	*39.5*
Missing	*8281*	*16.8*

Daily fruit and vegetable intake (portion)[†°]	**Mean**	***SD***	Min - Max[a]
Whole population	3.98	*2.3*	0 – 21.2
By gender			
Men (n=19,576)	3.47	*2.2*	0 – 19.5
Women (n=22,752)	4.39	*2.4*	0. – 20.1
By Census Metropolitan Area			
Calgary (n=3,535)	3.93	*2.40*	0 – 14.9
Montreal (n=10,638)	4.14	*2.54*	0 – 18.7

Ottawa (n=4,815)	4.03	*2.41*	0 – 16.3
Toronto (n=14,850)	3.86	*2.25*	0 - 20.1
Vancouver (n=8,490)	3.98	*2.34*	0 – 16.3

[†] Gender-differences significant at $P < 0.001$;
[o] CMA-differences significant at $P < 0.001$
[a] Due to restrictions on the dissemination of CCHS data imposed by the provider Statistics Canada, maximum values are the averaged maximum values of the fifteen individuals with the highest fruit and vegetable intake

As expected, positive correlations between sum of healthy and sum of unhealthy outlet densities (Pearson correlation coefficient = 0.947, *P*<0.001) were found, suggesting that participants with higher (lower) exposure to unhealthy outlets around home were also more likely to have higher (lower) exposure to healthy outlets. Gender-differences in foodscape exposure were found only for absolute measures, men being exposed to higher densities of both healthy and unhealthy outlets than women (See Annexe 1). CMA-differences were also observed, with Montreal, Toronto and Vancouver having greater densities of both healthy and unhealthy outlets, as well as a higher percentage of healthy outlets.

Regression analyses using the whole sample

In the whole sample (Table 2), the percentage of healthy outlets was positively associated with FVI (β=0.005; *P*<0.001). Similarly, absolute FFR density (β=-0.039; *P*<0.001) and FVS density (β=0.026; *P = 0.047*) were associated with FVI when models were adjusted for the overall outlet density. The FFR density model did, however, present some multicollinearity issues (VIF value of 11.1).

Overall, the Akaike Criterion Information (AIC) indicated the best model fit (i.e. lowest AIC) when using the relative measure, both with and without adjusting for overall outlet density.

Table 2 Associations between foodscape exposure and daily fruit and vegetable intake - Whole sample, Canada, 2007-2010 (N=49,403)

	β[a]	95% CI		VIF	AIC
Foodscape exposure measures					
Supermarkets density (*nb/km²)*					
Model 1 [b]	0.058	(-0.021	0.138)	1.2	65611
Model 2 [c]	0.122	(-0.005	0.249)	3.2	65612
Fruit and vegetable stores density (*nb/km²)*					
Model 1 [b]	0.024	(0.000	0.048)	1.0	65612
Model 2 [c]	0.026*	(0.000	0.051)	1.2	65614
Fast-food restaurants density (*nb/km²)*					
Model 1 [b]	-0.003	(-0.010	0.004)	1.1	65615
Model 2 [c]	-0.039***	(-0.060	-0.017)	11.1	65608
Sum of healthy outlets densities (*nb/km²)*					
Model 1 [b]	0.005	(-0.004	0.013)	1.1	65613
Model 2 [c]	0.012	(-0.004	0.028)	4.4	65615
Sum of unhealthy outlets densities (*nb/km²)*					
Model 1 [b]	0.000	(-0.006	0.005)	1.2	65615
Model 2 [c]	-0.013	(-0.032	0.005)	13.8	65615
Percentage of healthy outlets (%) [b]	0.005 ***	(0.002	0.008)	1.5	65600

* *P* < 0.05; ** *P* < 0.01; *** *P* < 0.001

[a] Unstandardized regression coefficient
[b] Model adjusted for gender, age, education level, marital status, ethnic origin, household size adjusted income, CMA of residence, and neighborhood material and social deprivations
[c] Model adjusted for gender, age, education level, marital status, ethnic origin, household size adjusted income, CMA of residence, neighborhood material and social deprivations, and overall outlet density

Interaction analyses

Significant interactions between gender and exposure variables were found only with relative measures (P<0.001), the percentage of healthy food outlets being more strongly related to FVI for men than for women. The interaction between CMA and relative measures of exposure, tested separately for men and women, was not significant among women. Inversely, for men, associations between the percentage of healthy outlets and FVI were weaker in Calgary, Ottawa, Vancouver (P<0.05), but not different in Toronto, compared to associations observed in Montreal.

Three population subsamples were therefore established to test relative measure-FVI associations: men from Calgary/Ottawa/Vancouver, men from Montreal/Toronto, and women from all five CMAs.

Regression analyses in the gender- and CMA-stratified samples (Table 3)

The percentage of healthy outlets was positively associated with FVI among men both in Toronto/Montreal (β=0.012; *P*<0.001) and in Calgary/Ottawa/Vancouver (β=0.008; *P*<0.001). Among women, the association was marginal (β=0.004; *P*=0.051).

Table 3 Associations [a] between foodscape exposure and daily fruit and vegetable intake in gender- and CMA-stratified samples, Canada, 2007-2010

	Women (n=27,241)		**Men** Montreal, Toronto (n=12,268)		**Men** Calgary, Ottawa, Vancouver (n=8,894)	
	β [b]	95% CI	β [b]	95% CI	β [b]	95% CI
Exposure						
% healthy outlets	0.004	(0.000;0.007)	0.012***	(0.006;0.018)	0.008 ***	(0.004;0.012)

*** P < 0.001
[a] Model adjusted for age, education level, marital status, ethnic origin, household size adjusted income and neighborhood material and social deprivations
[b] Unstandardized regression coefficient

Except for models run in Vancouver, Toronto and Ottawa among women, regression residuals were not spatially correlated, suggesting that the spatial structure was overall well accounted for by our modeling.

DISCUSSION

In the whole population sample, the percentage of healthy outlets was strongly associated with FVI (β=0.005; *P*<0.001). FFR density (β=-0.039; *P*<0.001) and FVS density (β=0.026; *P = 0.047*) were also related to FVI when models were adjusted for the overall outlets density, but those associations either faced multicollinearity issues or were weak. Overall, AIC indicated the best model fit when using the relative measure.

In this study, the relative measure of exposure was better correlate of FVI than absolute measures, in line with recent work exploring absolute and relative exposures in Australia (Mason, Bentley et al. 2013) and in the USA (Zenk, Powell et al. 2014). Whereas improved statistical significance may be an important aspect, use and usefulness of relative measures also requires better conceptual integration. So far, most research looking at the relationship between absolute measures of exposure and diet was driven by the “gravity model” (Cadwallader 1981) which asserts that closer destinations are more attractive because their access requires less financial and travel time investment. However, relative measures of exposure may be less prone to a strict ‘proximity’ and ‘gravity’ justification of use. The fact that individuals tend to be exposed simultaneously to both healthy and unhealthy food outlets points towards the relevance of looking at foodscape exposure from a competitive food choice environment viewpoint (Kubik, Lytle et al. 2003; Fox, Gordon et al. 2009). As the sight of calorie-dense food cues promotes the automatic desire for eating (Cohen and Farley 2008), unhealthy food choices may, to some extent, outweigh healthy ones. In parallel, the consumption norm, through the predominant food supply in the environment, drives messages about acceptable and unacceptable behaviours (Wansink 2004; Cohen and Farley 2008). To conform to the apparent norm, individuals who live in environments with a strong predominance of healthy food stores may adopt healthier diets than others living in environments with a predominance of unhealthy outlets.

Such statements should, however, be interpreted in the light of contextual factors which may modify the foodscape-FVI relationship. Indeed, the percentage of healthy outlets was strongly associated with FVI for men, but not for women. Women have been reported more likely to be nutritionally knowledgeable (Turrell 1997), to perceive nutrition as important when food shopping (Turrell 1997), and to engage in risk-reducing strategies (Mitchell and Boustani 1993). Consequently, they may be less responsive to the normative dimension driven by the foodscape.

CMA-differences in the magnitude of foodscape-FVI associations were further found, with a significantly stronger association for men living in Montréal and Toronto compared to men living in Calgary, Ottawa and Vancouver. Given that Montréal and Toronto are less sprawled than Calgary, Ottawa and Vancouver (Ross, Tremblay et al. 2007), and therefore potentially more 'walkable' (Camagni, Gibelli et al. 2002; Ewing, Schmid et al. 2003), one possible explanation could be that individuals' mobility moderate the foodscape-diet relationship at place of residence (Longacre, Drake et al. 2012).

Further research is however needed to both pinpoint the underlying causes of those gender- and CMA-variations, and rule out potential Canadian context specificity.

Limitations

First, given the cross-sectional nature of our study, we cannot exclude that significant associations may be due to reverse causation (i.e. FVI influencing residential migration to specific neighborhoods). Second, our FVI variable was aggregated across four food items obtained from a non-quantitative FFQ. Some misspecification problems may be expected, if the relationship between the four food items taken separately and the control variables are not homogeneous. Furthermore, portion sizes were not accounted for and over-declaration of variables obtained via FFQ have been reported. However, there is no a priori suspicion that the possible level of over-reporting would be correlated to exposure while holding covariates constant, and then reason to think our estimates are badly inflated. Third, as our subsample may not be fully representative of the whole urban population in Canada, cautious is required in generalizing those findings. Fourth, in order to rule out the large sample size as the primary cause of observed significant associations, the replication of our findings in other settings would be timely. Finally, foodscape exposure may have been underestimated, our study focusing solely on the residential neighborhood (Kestens, Lebel et al. 2010; Burgoine and Monsivais 2013). Accounting for individuals' daily mobility would help refine exposure assessment.

CONCLUSION

Our findings add to the evidence that relative exposures may be more appropriate than absolute exposures when exploring foodscape-diet associations. Policies sensitive to striking a better balance between healthy and unhealthy outlets may be more effective in encouraging fruit and vegetable consumption than policies seeking to alter access to either healthy or unhealthy outlets independently. More evidence, especially drawn from longitudinal studies, is needed, though. Overall, those findings encourage a more systematic use of relative measures when assessing foodscape influences on health. By highlighting gender and city differences in the foodscape-FVI relationship, they also underline the absence of one universal effect of the foodscape on diet, and positions sub-group analysis as a promising avenue for research.

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Conflict of interest statement

The authors declare that there are no conflicts of interest.

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Annexe 1 Foodscape exposure of CCHS participants, for the whole sample, and by sex or Census Metropolitan Area, Canada, 2007-2010

	Total	Men	Women	Calgary	Montreal	Ottawa	Toronto	Vancouver
	(N=49,403)	(n=22,162)	(n=27,241)	(n=4,038)	(n=12,309)	(n=5,589)	(n=17,290)	(n=10,177)
Densities	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Supermarkets°	0.24	0.25	0.24	0.21	0.26	0.15	0.25	0.28
(unit: /km²)	(0.28)	(0.29)	(0.27)	(0.24)	(0.25)	(0.15)	(0.32)	(0.30)
Fruit/vegetable stores°	0.19	0.19	0.19	0.01	0.32	0.03	0.14	0.29
(unit: /km²)	(0.86)	(0.84)	(0.87)	(0.01)	(1.54)	(0.19)	(0.55)	(0.86)
Fast-food restaurants†°	1.74	1.81	1.68	1.92	1.56	1.18	1.78	2.12
(unit: /km²)	(3.12)	(3.33)	(2.93)	(3.02)	(2.60)	(1.69)	(3.48)	(3.58)
Sum of healthy outlets†°	1.50	1.54	1.46	0.82	1.76	0.85	1.37	2.02
(unit: /km²)	(2.62)	(2.74)	(2.52)	(1.30)	(3.08)	(1.44)	(2.34)	(3.16)
Sum of unhealthy outlets†°	2.54	2.63	2.47	2.33	3.19	1.64	2.47	2.45
(unit: /km²)	(4.07)	(4.32)	(3.86)	(3.52)	(4.39)	(2.16)	(4.38)	(4.01)
% "healthy" outlets°	33.26	33.21	33.30	24.28	30.81	29.94	32.35	43.14
(unit : %)	(9.72)	(9.77)	(9.68)	(8.58)	(6.97)	(10.76)	(6.48)	(9.59)

† Gender-differences significant at $P < 0.001$
° Census Metropolitan Area-differences significant at $P < 0.001$

ARTICLE 3

Title: Associations between residential and non-residential foodscapes and fruit and vegetable intake

Submitted to *Public Health Nutrition*

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Conflict of Interest

None

ABSTRACT

Objective: To test whether densities of food outlets experienced around home (residential exposure) differ from those experienced in the subset of away-from-home visited places (non-residential exposure). To assess the association between fruit and vegetable intake (FVI) and non-residential exposure while adjusting for residential exposure.

Design: Cross-sectional. For men and women residents of the Montréal Census Metropolitan Area (MCMA), residential and non-residential foodscape exposures were assessed in the form of absolute (density of a particular outlet type) and relative (percentage of healthy outlets) measures, and compared using analyses of variance. Linear regression models adjusted for socio-demographics and residential exposure were used to test the associations between non-residential exposure (relative measure) and FVI, separately for men and women.

Setting: Four waves (2007-2010) of the Canadian Community Health Survey (CCHS), and the 2008 Origin-Destination (OD) survey.

Subjects: Men and women aged 18 and over, living in the MCMA.

Results: When away from home, both male and female participants were exposed to higher densities of outlets and a lower percentage of healthy outlets, compared to around home. The residential percentage of healthy outlets around home was associated with FVI when adjusted for non-residential exposure, for men only ($\beta=0.017$; P-value < 0.001). The non-residential percentage of healthy outlets was not associated with FVI.

Conclusions: These findings suggest that residential and non-residential exposures may be associated with FVI in different ways. They further add to the growing evidence that relative exposures around home may be good correlates of diet, especially among men.

Keywords

Food environment; Exposure assessment; Relative and absolute densities; Mobility; Fruit and vegetable intake

INTRODUCTION

In recent years, calls have been made for an improved modeling of the foodscape-diet relationship (Diez Roux 2004; Lytle 2009; McKinnon, Reedy et al. 2009). So far, most research has assessed how much *absolute* densities of particular outlet types, either healthy or unhealthy, relate to dietary outcomes. However, a more systematic use of *relative* densities of healthy and unhealthy outlets has been lately advocated (Mason, Bentley et al. 2013; Clary, Ramos et al. 2015). The usefulness of relative measures is justifiable from both a conceptual and a methodological standpoint. Food store choice describes a preference toward one (or a few) outlet(s) from a larger set of competing alternatives (Bhatnagar and Ratchford 2004). By putting into relation healthy and unhealthy outlets, relative measures help question how much individuals may preferentially opt for a healthy option in the simultaneous presence of unhealthy alternatives. Using absolute densities of a particular outlet type and controlling for the other types available may be another way to account for alternatives. However, because of high spatial correlation between outlet types (Rundle, Neckerman et al. 2009; Black, Carpiano et al. 2011; Clary, Ramos et al. 2015), problems of multicollinearity are likely to be introduced (Clary, Ramos et al. 2015). Combining exposures to healthy and unhealthy outlets through the use of an index is a more satisfying option (York 2012; Clary, Ramos et al. 2015). A growing literature using relative measures has consistently shown significant associations with various diet outcomes (Christian 2012; Mason, Bentley et al. 2013; Zenk, Powell et al. 2014; Clary, Ramos et al. 2015). Yet, the majority of these studies focused on the foodscape around home. Whereas the residential environment may be a meaningful geographical anchor point and a privileged area for implementing public health policies (Diez Roux 2001), individuals' daily mobility (Miller 2007) implies that a number of activities, including food shopping (Inagami, Cohen et al. 2006; Kerr, Frank et al. 2012), are undertaken beyond the residential neighborhood (Matthews 2010; Vallee, Cadot et al. 2010). Because the foodscape individuals experience away from home tends to be different than the one around home (Kestens, Lebel et al. 2010; Burgoine and Monsivais 2013), focusing on the residential foodscape alone may not provide an accurate picture of actual exposure (Perchoux, Chaix et al. 2013).

The activity space – or the subset of all locations within which an individual has direct contact as a result of his or her day-to-day activities (Golledge and Stimson 1997) – has been increasingly used to represent the environments people experience during their daily mobility (Sherman, Spencer et al. 2005; Flamm and Kaufmann 2006; Perchoux, Chaix et al. 2013). Detailed mobility information can be obtained by tracking individuals with Global Positioning System (GPS) receivers. Activity space exposure is then obtained using buffers around individuals tracks (Zenk, Schulz et al. 2011; Christian 2012) (i.e. the path area), or with use of other geometric forms, including convex hulls, or approximations of activity spaces using standard deviational ellipse (Zenk, Schulz et al. 2011). When only visited locations are known, but not travel routes, areas around those destinations have been taken into account, or convex hulls have been drawn. Only a few studies have investigated whether foodscape exposure accounting for daily mobility was related to diet (Zenk, Schulz et al. 2011; Christian 2012; Gustafson, Christian et al. 2013; Burgoine, Forouhi et al. 2014). Fast-food density within activity space (operationalised through daily path areas (Zenk, Schulz et al. 2011) or a combination of home, work, and commuting route environments (Burgoine, Forouhi et al. 2014)) was positively associated with fat intake in Zenk et al.'s study (Zenk, Schulz et al. 2011) and with takeaway food consumption in Burgoine et al.'s study (Burgoine, Forouhi et al. 2014), but not in Christian's study (Christian 2012) or when the activity space was operationalised as a standard deviational ellipse (Zenk, Schulz et al. 2011). Furthermore, the ratio of unhealthy relative to healthy stores densities in the daily path area was negatively associated with whole grain intake in Christian's study (Christian 2012), but not with any other dietary outcome, including fruit and vegetable, red meat or added sugar intakes, and not with any dietary outcome in Gustafson et al.'s study (Gustafson, Christian et al. 2013). In short, more research considering daily mobility is needed to advance our understanding of how foodscape exposures relate to diet.

The lack of individual-level mobility data in current health surveys has limited our capacity to assess activity space exposures. To address the shortage of mobility data, researchers have started using innovative predictive modelling in order to derive estimates of modeled exposure along commuting routes (Burgoine and Monsivais 2013; Burgoine, Forouhi et al. 2014) or in visited settings (Kestens, Lebel et al. 2010; Kestens, Lebel et al. 2012; Lebel, Kestens et al. 2012). Previous work has shown that people with similar individual and household characteristics and living in similar areas experience similar activity-based exposure patterns to food outlets (Kestens, Lebel et al. 2010). Using estimates of activity-space exposure may be a promising avenue to compensate for the lack of information on individuals' daily mobility.

Aim

Using data from the Origin-Destination (OD) wide-scale mobility survey in Montreal, Canada, the present study first tests whether densities of food outlets experienced around home (residential exposure) differ from those experienced in the subset of away-from-home visited places (non-residential exposure). Second, predictive models of non-residential exposure (relative measure) were calibrated with OD-participants, separately for men and women, and used to assess *estimates* of non-residential exposure of male and female participants of a health-survey (CCHS) in Montreal. The relation between fruit and vegetable intake (FVI) and the *estimated* non-residential exposure (relative measure) was assessed using multiple linear regressions and controlling for a wide range of socio-demographics and residential exposures. Analyses are presented separately for men and women.

Our related hypotheses were that: 1) non-residential exposure levels are significantly higher than residential ones; 2) relative measures in both the residential and the non-residential environments are predictors of FVI.

METHODS

Databases

The present work capitalised on three databases.

(1) The 2008 Origin-Destination (OD) is a computer-assisted phone-interview survey, which collects mobility data from individuals living in the Montréal Census Metropolitan Area (MCMA). One primary respondent provides information about visited destinations and travel modes for all members of the surveyed household aged four and above for the previous weekday. In each of the 108 geographical strata dividing the MCMA (formed by groups of sectors or census sub-divisions, as defined by Statistics Canada for the 2006 census), surveyed household are selected via random digit dialing. 66,124 primary respondents provided data for a total of 156 720 individuals (i.e. 4.1% of the targeted MCMA population).

(2) The Canadian Community Health Survey (CCHS) is a repeat cross-sectional survey from Statistics Canada. Since 2001, it collects information related to socio-demographic status and health determinants – including fruit and vegetable intake, among approximately 65 000 Canadians aged 12 years and above each year, using computer-assisted phone interview. Four CCHS cycles (2007 to 2010) were pooled for the present study.

(3) Foodscape data was obtained from the 2010 DMTI Spatial® EPOI (Enhanced Points of Interest) file, a dataset of businesses across Canada. For each listed food business, the EPOI file provides the name, geographic coordinates, and from one to six Standard Industrial Classification (SIC) codes based on the economic activities declared(Administration 2008). Using a SIC code- and name-based assignment method of categorization, ten categories of food outlets - supermarkets, grocery stores, convenience stores, bakeries, fruit and vegetable stores (FVS), specialty stores (e.g. butcher), natural food stores (NFS), fast-food restaurants (FFR), full-service restaurants (FSR) and cafés - were extracted from the EPOI dataset. Details about the extraction method have been published elsewhere (Clary and Kestens 2013). The dataset, validated in 2010 using ground-truthing, has shown a good capacity to assess local densities of outlets. Representativity of the dataset, that is, concordance between outlets present on the EPOI list and outlets observed on the field was 77.7% when relaxing on business names, small imprecisions in location (i.e. within the same census tract), and when compensating false negatives with false positives within the same outlet category and census tract (See (Clary and Kestens 2013) for more details).

Variables

Fruit and Vegetable Intake

The daily fruit and vegetable intake (FVI) measure was obtained by calculating the sum of self-reported number of portions of “fruits (excluding fruit juices)”, “green salad”, “carrots”, and “other vegetables (excluding carrots, potatoes, and green salad)” of the CCHS Food Frequency Questionnaire. Numbers of portions were freely reported per month, week or day. All data were transformed into daily consumptions and summed up to obtain a continuous daily FVI variable.

Foodscape exposure

The outlet types derived from the EPOI database were dichotomised as either a "healthy" option or an "unhealthy" alternative. "Healthy" restrictively referred to "outlets that favor complete meals with fruit and vegetable options", and included supermarkets, FVS, NFS, and grocery stores. Inversely, "outlets allowing for complete meals but offering few or no fruit and vegetable options" were considered as competitive "unhealthy" options, and included convenience stores and FFR. Bakeries and specialty stores, which were assumed not to offer complete meal possibilities, were not considered has "unhealthy" competitors but rather complementary purchasing options to the "healthy" outlets. Consequently they were excluded from the construction of relative measures. Besides, FSR and cafés are heterogeneous regarding how much fruit and vegetable options they offer. Because the assignment method used to categorize those outlets was insensitive to those variations, they were also trimmed out.

For each retained food outlet category (supermarkets, FVS, NFS, grocery stores, convenience stores and FFR), a continuous density surface was computed using kernel density estimations in Crimestat v.3.3. Densities were computed using a quartic kernel with an adaptive search radius distance – or bandwidth (Carlos, Shi et al. 2010) - including 5% of the closest neighbors. These criteria were chosen in accordance with previous studies (Kestens, Lebel et al. 2012; Lebel, Kestens et al. 2012), and because visual evaluation of kernel densities pointed towards possible over- and under-smoothing with larger (i.e. 10% of neighbours) or smaller (1%) bandwidths respectively. For OD-participants, absolute measures of density for each outlet category were extracted at the geographic coordinates of each visited place (including home), using ArcGIS v10.1. For CCHS-participants absolute measures of density at place of residence were extracted at the centroid of the 6-digit postal code of residence. For each visited place including home, a relative measure was computed as the percentage of healthy outlets – i.e. summed densities of healthy stores divided by the total summed densities, for both OD- and CCHS-participants.

For OD-participants, residential and non-residential exposures for each relative and absolute measures of density were computed as the score of exposure at home and the mean score of exposure at all visited places excluding home, respectively. Individuals visiting a same location were attributed the same level of exposure, regardless of individuals' time spent at that place.

For CCHS-participants, residential exposures were computed as the score of exposure at home. However non-residential exposures could not be assessed directly, since CCHS surveys did not provide any information about individuals' mobility. Previous literature has shown that foodscape exposure could be modelled using individual, household and environmental variables (Kestens, Lebel et al. 2010; Kestens, Lebel et al. 2012; Lebel, Kestens et al. 2012). Both OD- and CCHS-participants were drawn from the same original population (Montreal Census Metropolitan Area). They share similar characteristics (table 1). Consequently, data available for OD-participants was used to impute missing information on non-residential exposure (relative measure) for CCHS-participants. Multiple Imputation (MI) was used under the normality assumption to impute, separately for men and women, estimates of non-residential exposure from a wide range of individual, household and environmental variables characterising the place of residence (see Annexe 1). MI is a Monte Carlo technique. It constructs several completed data sets from the original incomplete data by replacing the missing values in each data set by random draws from the conditional distribution of the missing data (given observed data). Each of the simulated complete datasets is then analyzed separately by standard methods, and the results are combined to produce estimates and confidence intervals that incorporate missing-data uncertainty - i.e. that account for the differences within (variation due to sampling) and between (variation due to imputation) data sets. OD- and CCHS-databases were consequently merged and then stratified by sex. MI were performed with 20 iterations, since the percentage of missing values for non-residential exposure variables (i.e. the percentage of CCHS-participants) was about 20% after both databases were merged (Allison 2012). All individuals, household and environmental variables common to both dataset were used as predictors for the missing information (Annexe 1).

Socio-demographic variables

Age ([18-29], [30-44], [45-64], [65 and over]), educational level (less than secondary grade, secondary degree, post-secondary grade, post-secondary degree), ethnic origin (White, Asian, Black, other), marital status (single person, couple without children, couple with children, single parent with children, other), household size adjusted income (low, mid-low, mid-high, high, no answer), and both material and social neighborhood deprivation were included in the models. Household size adjusted income was computed using both annual household income (12 categories) and the number of household members (three categories). Missing income values were kept by using a “no answer” category. The 2006 material and social dimension of the Pampalon deprivation Index (Pampalon, Hamel et al. 2009) available at the dissemination area level were extracted at the 6-digit postal code level to provide neighborhood material and social deprivation variables.

Statistical analyses

First, residential and non-residential densities (absolute and relative) were derived and compared among OD-participants, using analyses of variance. Absolute measures, whose distributions were skewed, were transformed into logarithms before variance analyses, in order to approximate normality. Second, multiple linear regressions were used on CCHS-participants to test, separately for men and women, the association between FVI and the *estimated* percentage of healthy outlets in the non-residential environment. Both regression models were adjusted for age, educational level, marital status, ethnic origin, income, and neighborhood material and social deprivations. In order to account for the variability in the way the percentage of healthy outlets in the residential neighborhood may independently affect participants' FVI, models were further adjusted for residential exposure. All statistical analyses were performed in SPSS, v20.0.

RESULTS

Among the 156,720 OD-participants, those who were not primary respondent (n=90,596), i.e. whose spatial behaviours were reported by a third person, were excluded from our sample, because some misrepresentation may be expected. Besides, the assumption of independence of observations would have been violated otherwise. Individuals who were either aged under 18 (n=42,445), or who did not leave home (n=29,333), or who had a travel destination outside of the MCMA (n=2,937) were also excluded. Among the 45,668 OD-participants in our sample, 103 had missing observations on relevant variables and were deleted. 45,565 OD-participants were used for analyses.

Among the 13,058 CCHS-participants aged 18 or more and living in the MCMA, 749 (5.7%) had missing values on FVI, 466 (3.6%) on ethnic origin, 452 (3.5%) on educational level and 53 (0.4%) on marital status, and were excluded. A total of 11,809 individuals were kept for analysis.

OD and CCHS populations' characteristics are described in Table 1.

Table 1 Descriptive statistics for OD and CCHS participants

	OD				CCHS			
	FEMALE (n=26,751)		MALE (n=18,814)		FEMALE (n=6,611)		MALE (n=5,198)	
	N	%	n	%	n	%	n	%
Age								
18-29	2975	11.1	2216	11.8	1119	16.9	1018	19.6
30-44	7928	29.6	5712	30.4	1564	23.7	1483	28.5
45-65	11651	43.6	8264	43.9	2197	33.2	1723	33.1
65+	4197	15.7	2622	13.9	1731	26.2	974	18.7
Household structure								
Single	6830	25.5	4683	24.9	2384	36.1	1508	29.0
Couple	8290	31.0	6564	34.9	1753	26.5	1662	31.2
Couple with children	7546	28.2	5405	28.7	1516	22.9	1389	26.7
Single parent	2025	7.6	666	3.5	547	8.3	275	5.3
Other	2060	7.7	1496	8.0	411	6.2	404	7.8
Working status								
Full-time worker	13339	49.9	12079	64.2	3537	53.5	3441	66.2
Part-time worker	2449	9.2	844	4.5	588	8.9	379	7.3
Other	10963	40.9	5891	31.3	2486	37.6	1378	26.5
Ethnical origin								

White	.	.	.	.	5883	89.0	4515	86.9
Asian	.	.	.	.	199	3.0	154	3.0
Black	.	.	.	.	213	3.2	188	3.6
Others	.	.	.	.	316	4.8	341	6.6
Education								
<than secondary	.	.	.	.	1245	18.8	807	15.5
Secondary grad.	.	.	.	.	884	13.4	630	12.1
Other post-second.	.	.	.	.	440	6.7	371	7.1
Post-secondary grad.	.	.	.	.	4042	61.1	3390	65.2
Household income								
Low	.	.	.	.	549	8.3	315	6.1
Mid-low	.	.	.	.	1241	18.8	716	13.8
Mid-high	.	.	.	.	1945	29.4	1605	30.9
High	.	.	.	.	1927	29.1	2033	39.1
No answer	.	.	.	.	949	14.4	529	10.2
Fruit and vegetable intake					Mean	SD	Mean	SD
Number of portions/day	.	.	.	.	4.62	2.55	3.54	2.40

Residential and non-residential exposures among OD-participants

For both women and men from the OD-survey, absolute densities of food outlets were significantly higher away from home than around home (Table 2). The strongest difference was observed for FFR (+201% for women and +204% for men). Inversely, the percentage of healthy stores was slightly but significantly lower away from home.

Table 2 Descriptive statistics for residential and non-residential exposures for OD-participants

	Women (n=26,751)			**Men** (n=18,814)		
	Residential exposure	Non-residential exposure	*Diff.*	Residential exposure	Non-residential exposure	*Diff.*
	Mean (S.D.)	Mean (S.D.)		Mean (S.D.)	Mean (S.D.)	
Density (n/km²)						
Supermarkets	0.30 (0.28)	0.36 (0.26)	*+20.0%**	0.31 (0.29)	0.36 (0.26)	*+16.1%**
Fruit/vegetable stores	0.37 (1.46)	0.58 (2.40)	*+56.8%**	0.38 (1.14)	0.61 (2.36)	*+60.5%**
Grocery stores	1.21 (1.77)	1.96 (2.33)	*+62.0%**	1.32 (1.92)	2.07 (2.40)	*+56.8%**
Natural food stores	0.20 (0.32)	0.38 (0.47)	*+90.0%**	0.22 (0.35)	0.41 (0.49)	*+86.4%**
Fast-foods	1.75 (2.65)	5.27 (9.70)	*+201.1%**	1.91 (2.93)	5.8 (10.13)	*+203.7%**
Convenience stores	1.93 (2.29)	2.66 (2.57)	*+37.8%**	2.07 (2.45)	2.75 (2.62)	*+32.9%**
Healthy outlets	2.08 (3.15)	3.28 (4.33)	*+57.7%**	2.24 (3.16)	3.45 (4.40)	*+54.0%**
Unhealthy outlets	3.68 (4.57)	7.92 (11.57)	*+115.2%**	3.98 (4.98)	8.56 (12.05)	*+115.1%**
%healthy outlets	31.73 (7.56)	31.48 (8.54)	*-0.8%**	31.85 (7.60)	31.38 (8.51)	*-1.5%**

* Significant difference (ANOVA, $p<0.001$) between residential and non-residential exposures

Associations between FVI and residential and non-residential exposures among CCHS-participants

In fully-adjusted regression models (Table 3), there was no evidence of an association between FVI and the *estimated* percentage of healthy outlets in the non-residential area, neither for women nor for men. Inversely, the percentage of healthy outlets around home was positively associated with FVI (β=0.017; p<0.01) after adjustment for the *estimated* percentage of healthy outlets in the non-residential area, but only for men.

Overall *(results not shown)*, FVI was positively associated with educational level and income, and negatively associated with living in a more socially (for women) and more materially (for men) deprived neighborhood. For men only, FVI was positively associated with being in a couple with or without children compared to being single. For women only, FVI was negatively associated with being Black or “other” compared to being White.

Table 3 Associations between foodscape exposure and fruit/vegetable intake, CCHS participants, Montreal, 2007-2010

	Women				**Men**			
	β[a]	95% CI		p-value	β[a]	95% CI		p-value
% healthy outlets								
Non-residential (estimated density) [b]	0.002	-0.01	0.02	0.810	-0.001	-0.01	0.01	0.891
Residential [c]	0.005	-0.01	0.02	0.301	0.017	0.01	0.03	0.001

[a] Unstandardized β-coefficient

[b] Adjusted for age, educational level, marital status, ethnic origin, income, neighborhood material and social deprivations,
and foodscape exposure in residential area

[c] Adjusted for age, educational level, marital status, ethnic origin, income, neighborhood material and social deprivations and foodscape exposure in non-residential area

DISCUSSION

When away from home, participants got exposed to foodscapes that were significantly different from those experienced around home, in line with previous research (Kestens, Lebel et al. 2010; Burgoine and Monsivais 2013). Both for women and men, levels of exposure to each type of food outlets under study were higher in visited places, with the greatest increase of exposure for FFR (+201% and +204% respectively). The percentage of healthy outlets experienced away from home was slightly lower than around home. These findings reinforce the mounting evidence that non-residential exposure deserves more attention (Perchoux, Chaix et al. 2013).

We further found that the percentage of healthy outlets was positively related to FVI in the residential area after controlling for non-residential exposure, but only for men ($\beta=0.017$; $p<0.01$). This finding adds up to the growing evidence that relative exposures to healthy and unhealthy outlets in the residential area are correlates of dietary outcomes (Babey, Wolstein et al. 2011; Mercille, Richard et al. 2012), including fruit and vegetables (Mason, Bentley et al. 2013; Clary, Ramos et al. 2015). The observation of such an association after controlling for the non-residential percentage of healthy outlets suggests that residential exposure may relate to FVI independently from other contextual exposures.

Inversely, we did not find significant associations between non-residential exposure and FVI, in line with other studies (Christian 2012; Gustafson, Christian et al. 2013). The foodscape may therefore relate to diet differently in residential and non-residential areas. By way of explanation, other dimensions, beyond the relative exposure to healthy and unhealthy outlets, may play a role in food choices (Caspi, Sorensen et al. 2012). For instance, in workplace contexts, where time considerations are of importance, outlets offering a quick delivery of ready-to-eat foods may be perceived as particularly attractive (e.g. fast-food restaurants, any store providing foods quickly reachable, payable and eatable). Under that perspective, it may appear relevant to build relative measures that would put into relation outlets according to their ability to quickly deliver fast-foods. Yet, the relative measures used here and in other studies have not considered those complementary and possibly competitive motives for food store choice. Exploring alternative ways of building relative measures of exposure that would better cease individuals incentives for patronising outlets when in the non-residential environment, may be an interesting avenue in future studies.

Moreover, we found that residential foodscape exposure related to FVI only for men, consistently with the rare studies that have explored gender differences in the foodscape-diet relationship (Macdonald, Ellaway et al. 2011; Sharkey, Johnson et al. 2011). There is actually some evidence that normative influences on intended food choices (Croker, Whitaker et al. 2009) and volume of intake (Wansink and Cheney 2005; Hermans, Herman et al. 2010) may be stronger for men. In an experimental study, Croker et al. demonstrated that intentions to eat fruit and vegetables were influenced by normative information only in men (p=0.011). In view of these observations, the relative amount of healthy and unhealthy outlets around home may be viewed as a normative benchmark to gauge the 'normal' or 'appropriate' food outlet choice to do.

Our findings should be interpreted in light of some methodological and conceptual shortcomings. First, the non-residential foodscape exposure used for CCHS-participants was not observed but *estimated*. Because the dependent variable (FVI) was not available for OD-participants, it was not included in the Multiple Imputation modeling. Resulting imputed values of foodscape exposure for CCHS-participants may therefore not have the same relationship to the FVI variable as 'true' observed values possibly would. Reduction of the strength of the relationship between FVI and foodscape exposure due to the use of an estimated variable is to be expected and may explain the absence of significant associations. The replication of this work using primary databases would be welcome. Second, our conceptualisation of the non-residential area, which did not consider travel routes, may have incompletely captured the foodscape experienced by participants when away from home. However, a recent study did not find any significant associations between FVI and relative foodscape exposure in the daily path area either (Christian 2012). Third, working-day trips may significantly differ from non-working day trips (Kerr, Frank et al. 2012). Because OD-participants travel reports only concern week days, the representation of non-residential exposure is only partial. Finally, data obtained both from CCHS and OD surveys were self-declared, with the inherent risk of data misreport.

CONCLUSION

We found that people experience higher densities of food outlets away-from-home compared to around home. These findings confirm the need to more systematically account for non-residential exposure in foodscape exposure assessment. FVI was linked to the percentage of healthy outlets in the residential area, at least for men, but not in the non-residential environment. Residential and non-residential exposures may influence individuals' FVI in different ways. More research that would confirm those findings would be timely, especially using primary databases.

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ANNEXE

Annexe 1 – Description of the individual, household and residential environment variables used to estimate non-residential exposure of CCHS-participants

	Source	Variables	Spatial unit
Individual and household variables	2007-10 CCHS survey	Sex	N/A
		Age	
		Working status	
		Household structure	
Characteristics of place of residence	Census 2006	Proportion of people age 65 and over	Characteristics of the residential environment, provided by the 2006 census at census tract (CT) or dissemination area (DA) scale, have been extracted in an 800 meter-road-network buffer around residential 6 digit-postcodes' centroid. Scores were weighted proportionally to the surface area of the overlap between the buffer zone and CT/DA.
		Proportion of single persons in the population 15 years of age and over	
		Proportion of single parent families	
		Proportion of dwellings needing major repair	
		Proportion of buildings built before 1946	
		Proportion of individuals speaking English at home	
		Proportion of people having moved last year	
		Proportion of immigrants	
		Proportion of people without certificate, diploma or degree, in the population 25 years of age and over	
		Mean household income	
		Proportion of active female mass transit in the population 15 years of age and over	
		Material deprivation, based on the Pampalon Deprivation Index	
		Social deprivation, based on the Pampalon Deprivation Index	
	DMTI 2008	Connectivity, as the number of three-ways intersections per buffer area	
		Connectivity, as the number of four-ways intersections per buffer area	
		Land use mix, as an entropy index of land use mix	
		Commercial density	Variable-radius buffer: adaptive Kernel Density Estimation with use of 5% neighbors and a quartic function, extracted at residential 6 digit-postcodes' centroid

CHAPTER 6. DISCUSSION

6.1. Executive summary and key findings

Over the last decades, westernised countries have witnessed significant changes in dietary behaviours, both regarding the quality of the diet and the mode of consumption (Chevassus-Agnès 1994; USDA 1998; Harnack, Stang et al. 1999; HCSP 2000; Popkin and Nielsen 2003; Nielsen and Popkin 2004; Cordain, Eaton et al. 2005; Garriguet 2007; Wells and Buzby 2008). There has been growing awareness that these changes have happened too quickly on an evolutionary time scale for the human genome to adapt (Cordain, Eaton et al. 2005). The discordance between our modern diet and the nutritional needs dictated by our genotype has given rise to a wide range of contemporary chronic disorders, like cardiovascular diseases, type 2 diabetes, and certain cancers (Dawber, Meadors et al. 1951; Desor, Greene et al. 1975; Keys, Menotti et al. 1986; Hill 1987; Block, Patterson et al. 1992; Slattery, Boucher et al. 1998; Birch 1999; Mente, de Koning et al. 2009; Rose, Bodor et al. 2009; Lee, Kim et al. 2011). Such discordant – more commonly termed *unhealthy* – dietary behaviours have been considered as one of the most pressing public health problems worldwide (WHO/FAO 2003). Yet, there is a lack of guidance on how to make populations adopt behaviours that would be more respectful of their nutritional needs, that is, more in line with global and national recommendations in terms of nutrition.

Food outlet distributions both in areas where people live (residential foodscape) and where they undertake their daily activities (non-residential foodscape) have been hypothesised to play a key role in shaping dietary behaviours (Story, Kaphingst et al. 2008). The adjectives 'obesogenic' (e.g. (Lake and Townshend 2006; Burgoine, Alvanides et al. 2011; Mackenbach, Rutter et al. 2014)) and 'healthy' (e.g. (Story, Kaphingst et al. 2008)) commonly used to describe these foodscapes are evocative of their acknowledged influence on health behaviours. Yet, which and how specific aspects of those environments exert positive or negative impacts on dietary behaviours has not been agreed upon (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012). Accordingly, we are currently unable to provide guidance on how the foodscape should be altered in order to encourage the adoption of healthier food choices. To address this gap, more evidence on the way the foodscape shapes dietary behaviours, driven by a sound conceptual framework (Frohlich, Mykhalovskiy et al. 2004), is needed

The assumptions tested in the present thesis have emerged from a broad conceptual proposal recognising that food choices are made by individuals from alternatives available in a certain use situation (Arganini, Turrini et al. 2012). Our conceptual proposal features two interrelated ways the foodscape influences the decision to opt for healthy or less-healthy food options. First, the type, location, prices charged, services provided and point-of-sale atmosphere of healthy and unhealthy outlets render these outlets differentially accessible to individuals seeking to make the best possible use of their foodscape. Yet, individual's limited ability to acquire and effectively utilise the information displayed in their environment paves the way for a second set of influences on decision-making regarding where and what to buy. Frequent exposure to unhealthy outlets may stimulate automatic interests for unhealthy food sources via biological predispositions. Exposure to overwhelming amounts of food options may put individuals in discomfort as to where to shop for food, and push them to mechanically repeat past choices. Finally, food choice is vulnerable to social conformism, referred to as *norms of appropriateness* (Herman, Roth et al. 2003; Bhatnagar and Ratchford 2004). The foodscape is not exogenous and predetermined. Instead, outlets owe their existence to their economic viability, which is itself highly dependent on consumers' purchases. Put differently, the foodscape is a materialised reflection of consumers' patronage behaviours overtime. As a consequence, relative densities of healthy and unhealthy outlets in individuals' environment may drive a normative message about which outlet types are popular and, therefore, "appropriate" to use. This latter perspective has however been little investigated in the public health field.

Accordingly, the research presented in this thesis has explored the following hypotheses in a Canadian urban context: individuals' fruit and vegetable intake is related to the percentage of the outlets offering a wide range of fruit and vegetable options in 1) their residential environment and 2) their non-residential environment. A few studies have suggested that the foodscape-diet relationship may be stronger for men than women (Macdonald, Ellaway et al. 2011; Sharkey, Johnson et al. 2011). Literature in environmental psychology has also highlighted how men especially tend to unconsciously rely on normative information implicitly driven by the environment to help their decision about food choice (Wansink and Cheney 2005; Croker, Whitaker et al. 2009; Hermans, Herman et al. 2010). For instance, Croker et al. observed that implicit norms of what should be the right amount of fruit and vegetables to consume actually influenced the intended consumption of fruit and vegetables among men but not women (Croker, Whitaker et al. 2009). Therefore, we have further tested whether gender differences in the relationship between foodscape exposures and fruit and vegetable intake would be observed.

In accordance with our first hypothesis, we provided evidence of a positive association between the percentage of healthy outlets around home and fruit and vegetable intake, in the five largest CMAs of Canada. Furthermore, we found stronger associations for men, consistent with existing literature (Croker, Whitaker et al. 2009; Macdonald, Ellaway et al. 2011; Sharkey, Johnson et al. 2011). However, fruit and vegetable intake was not related to the non-residential foodscape, neither for men nor for women.

6.2. General interpretations and future research perspectives

Our empirical research has provided evidence of the need for more systematically considering relative exposures to healthy and unhealthy outlets when seeking to understand how the residential foodscape relates to dietary behaviours. These findings are supported by a study recently performed in London that looked at spatial variations in the parameter estimates of the association between residential foodscapes and fruit and vegetable intakes, using geographically weighted regressions (GWR) (See Appendix II – Clary et al. *Submitted*). When relative densities to healthy and unhealthy outlet measures were used to model fruit and vegetable intake, the spatial variation in parameter estimates was low and all local coefficients were positive. In contrast, when absolute densities of healthy and unhealthy outlets taken separately were used, estimates fluctuated from highly positive to highly negative across the study area. By way of explanation, it was suggested that considering either healthy or unhealthy exposures independently from each other may give rise to *omitted variable bias* (Wooldridge 2012). As food outlets tend to cluster, exposure to healthy outlets may actually confound the relationship of exposure to unhealthy outlets and diet (and vice-versa). In light of this, spatial variations in parameter estimates of absolute healthy or unhealthy food environment exposure measures with diet may result from not controlling for the alternate exposure. This view is supported by smaller variations in local regression coefficients observed when accounting for the (un)healthy alternative (use of relative measure).

Because in this doctoral research we used continuous measures of foodscape exposure, the detection of possible threshold or saturation effects in the foodscape-diet relationship has been rendered impossible. In their 2013 paper, Mason et al. (Mason, Bentley et al. 2013) have split their relative measure of exposure (percentage of healthy stores) into three categories approximating tertiles, but using integer cutpoints: 0-10%, >10–15% and <15%-22%. The authors found that, for households in an area with between 10% and 15% of healthy outlets, the adjusted odds of healthier purchasing were 48% higher than those of households in an area with no more than 10% healthy food outlets (adjusted OR=1.48, 95% CI 1.12 to 1.96). However, the magnitude of the association for those living in areas with the greatest relative number of healthy food stores (i.e. <15%-22%) was fairly similar to that estimated for the middle category of the relative measure (i.e. >10–15%). Mason et al.'s findings suggest that the relationship may not be linear between the percentage of healthy outlets and healthy purchases, with possible saturation effect above a value of 10% healthy stores. Yet, it is not excluded that in some hypothetical areas where the percentage of healthy outlet would have been higher than 22%, the adjusted odds of healthier purchasing would not have been higher than those of households in an area with no more than 22%. Research that would look more in detail at the existence of meaningful cut-offs in exposure values above and under which the association with dietary intakes changes would be timely.

Overall, the doctoral research presented here has provided strong evidence of associations between relative measures of exposure to healthy and unhealthy outlets and dietary behaviours, consistent with a small but growing body of empirical research (Mason, Bentley et al. 2013; Mercille, Richard et al. 2012; Babey, Wolstein et al. 2012). Yet, traditional conceptual proposals on foodscape and dietary behaviours fail to provide guidance in the interpretation of such associations. By considering the influences of healthy and unhealthy food sources independently of each other, these proposals do not offer insights on the reason why healthy and unhealthy measures of exposure, when put into relation as a ratio, relate to the way individuals eat. Our findings hence challenge how foodscapes' influences on health behaviours have been conceptualised until now. The conceptual proposal introduced in Chapter 3 was an attempt to address this gap. We have proposed to look at dietary behaviours as the expression of choices toward one or a few food option(s) from the larger set of healthy and unhealthy options provided by the environment. Doing so, we have encouraged better considering what the foodscape has to offer as a whole, rather than focusing a priori on specific outlet types. We have also suggested that (un)healthy food choices are shaped by the foodscape in two distinctive ways. First, at the time of choice, outlets' characteristics render healthy and unhealthy outlets variably accessible to individuals desiring to purchase food but having their own constraints, means and preferences. Second, foodscape exposure within daily-path help individuals to evaluate and re-evaluate food acquisition possibilities (e.g. by building their foodscape literacy), to form intentions (e.g. by stimulating desire to eat), and to crystallize the consciously or unconsciously motivated food choices they subsequently make (e.g. by driving normative messages regarding popular choices to make). Doing so, our conceptual proposal draws connections between the time-space flow of foodscapes' *exposures*, and the decision-making process based on *access* assessment which individuals rely on when it comes to choosing where to purchase and what to eat.

Although our empirical findings that relative densities of healthy and unhealthy outlets around home relate to fruit and vegetable intake are consistent with our conceptual proposal, they did not allow us to fully validate the assumption that the foodscape exerts normative influences on dietary behaviours in the view of the following. First, whether relative densities of healthy and unhealthy outlets strictly reflect foodscape's normative dimension remains to be proven. Qualitative studies in the field of environmental psychology would certainly help to improve our understanding in this regard. Second, because our findings rely on cross-sectional data, we cannot ignore that they are susceptible to reverse causation. We discuss here two possible scenarios. On one hand, the relative densities of healthy and unhealthy outlets may influence migration to specific residential neighborhoods, referring more broadly to *residential selection bias*. In other words, people having greater consumption of fruit and vegetable may choose to live in places where the relative presence of outlets selling a wide range of fruit and vegetables is higher (independently of socioeconomic and demographic confounding, which have been accounted for in our models). Given that men are less concerned by nutritional considerations when food shopping than women (Nayga 1997; Turrell 1997), the premise according to which men only would choose their place of residence depending on the nature of the surrounding foodscape is questionable, although not excluded. On the other hand, individuals may modify their local foodscape through their purchasing behaviours. Areas with inhabitants eating greater amount of fruit and vegetable may stimulate this market niche and generate a greater number of outlets selling fruit and vegetable in the surroundings. We have earlier on argued that this is actually very likely, since the foodscape is under the market law. However, that does not rule out the possibility for people to be influenced, in turn, by this foodscape. What would make local residents (particularly men) eat a more similar way than individuals living further away, if not an influence from the residential environment they share? Besides, in the current context of facilitated mobility (Miller 2007), individuals tend to shop for food and eat relatively far from home (Day 1973; Inagami, Cohen et al. 2006; Hillier, Cannuscio et al. 2011; Kerr, Frank et al. 2012). As a consequence, a given residential foodscape will tend to be transformed not only by its local residents, but also by passersby who live elsewhere but carry out activities locally (whether working, visiting friends, etc.). If residents' fruit and vegetable intake is associated to a residential foodscape partly shaped by non-residents, then, we may reasonably assume that the association is likely to result from foodscape influences on dietary behaviours. Overall, evidence of the causal link between the foodscape and dietary behaviours is required, what could be gained from longitudinal studies.

Our empirical work further shows that the percentage of healthy outlets relates differently to fruit and vegetable intake among men and women. Women are more likely to be nutritionally knowledgeable (Turrell 1997; Nayga 2000), to perceive nutrition as important when food shopping (Nayga 1997; Turrell 1997), and to engage in risk-reducing strategies (Mitchell and Boustani 1993) and bargain-finding (Mortimer and Clarke 2011). In sum, women tend to be more thoughtful and reflective about their food choices, while men tend to rely more on low-involvement strategies (Beardsworth, Bryman et al. 2002; Mortimer and Clarke 2011). This is compatible with the idea of men being more sensitive to unconscious messages driven by their residential foodscape, although further research would be timely to understand the very reason why men and women tend to relate differently to their food environment.

Especially, one may question the innate (natural predisposition) or acquired (social roots) character of such differences. Individual variations in the response to food cues (Beaver, Lawrence et al. 2006), due to differential neural predispositions such as reward-sensitivity – i.e. sensitiveness to the reward properties of food (Paquet, Daniel et al. 2010), may provide a potential explanation for such differences. These differences may also be rooted in the social processes that fuelled the long history of gender-based inequalities in health (Denton, Prus et al. 2004). This latter perspective is to be considered in parallel with the work that has documented socioeconomic differences both in food patterns (Steele, Dobson et al. 1991; Roos, Lahelma et al. 1998; Martikainen, Brunner et al. 2003), and in the relation to the foodscape (e.g. (Morland, Wing et al. 2002)). Additionally, reasons for such gender differences may not exclude the stronger pressure on body image that women experience in westernised societies (Rozin and Fallon 1988; Ostovich and Rozin 2004). Overall, the very reasons for such gender differences would need further investigation.

Finally, our findings of a positive relationship between relative exposure and diet cannot be extended to the non-residential environment, since we did not find any association between non-residential exposures and fruit and vegetable intake. A greater understanding of the reasons why such relationship holds in residential but not in non-residential environments would be timely. Fried wrote that “among the many settings for human behaviour, the residential environment is distinctive ” (Fried 1982). More specifically, he emphasizes how this latter environment is integral to people’s identity (Fried 1982). If so, it may not be surprising that the way people eat reflects the nature of their residential foodscape. However, it remains unclear whether the home surroundings derive their singularity from their physical resources, the social interactions they encourage, or some symbolic properties (or a mixture of the three). Therefore, the relative contribution of the residential foodscape exposure to broader foodscape exposures needs further exploration.

6.3. Implication for public health policies

The health promotion discourse has long acknowledged the environment as key in the shift towards healthier behaviours (Wang, MacLeod et al. 2007; WHO 2008). In practice, though, public health nutrition policies have often embraced approaches in favour of public awareness and individual skills development (MacRae 2011). There is substantial evidence that learning about nutrition can bring individuals' diet closer to national and global nutrition guidelines (Hawkes 2013). Yet, in the current context of unflagging epidemic of nutrition-related diseases, exploiting the potential for the foodscape to act as a vector for nutritional change could be beneficial for populations.

In 2000, Pothukuchi and Kaufman wrote that "the food system is notable by its absence from the writing of planning scholars, from the plans prepared by planning practitioners, and from the classrooms in which planning students are taught" (Pothukuchi and Kaufman 2000). In addition, the authors highlighted the lack of a systematic approach to issues of access to nutritious food in populations, often handled on a case-by-case basis (Pothukuchi and Kaufman 2000). In Canada, like in other countries in the industrial world, the foodscape remains largely organized around private enterprises, and driven by market laws (MacRae 2011). Given that nutritious food is a biological requirement for life, it is actually surprising that national and local governments do not employ more of their land use power to mitigate the epidemic of unhealthy dietary behaviours. Among the likely reasons, Pothukuchi and Kaufman have pointed out the lack of practical guidance for investments and legislation (Pothukuchi and Kaufman 2000).

Attracting a new grocery store or supermarket in underserved areas has been one of the few suggestions made with intent to improve dietary outcomes. Such strategy has, however, shown mitigated results (Cummins, Petticrew et al. 2005; Wang, MacLeod et al. 2007; Cummins, Flint et al. 2014). Another suggestion has been to force the adoption of healthier dietary behaviours by regulating the concentration of food outlets like fast-food restaurants around specific areas (mostly youth-oriented facilities such as schools (Ashe, Jernigan et al. 2003)). We may, however, question the extent to which zoning bylaws are generalizable to urban populations as a whole, as this would possibly imply to simply ban certain outlet types across cities. Yet, this may be inexpedient for two reasons. First, in our western societies dominated by capitalist ideologies, freedom of trade would surely stand in the way of such restrictive regulations. Second, no food, and therefore food outlet, is fundamentally to be banned for a diet to be healthy. Sugar and fat have helped build healthier nations in the past by representing easily assimilable sources of energy for the body (Weill 2007). What makes them at risk nowadays is not so much their very nature that their overconsumption. Individuals with special food requirements aside, a healthy diet is characterised by the respect of maximum and minimum quantities for different food groups, rather than on dismissing some of them. As fallout from that, no outlet type should be ruled out per se. Instead of banning certain types of outlet, creating environments that would encourage the adoption of a balanced diet appears more expedient.

We have highlighted that “unhealthy” outlets are currently predominant in the Canadian urban foodscape. On average, adults living in the five biggest CMAs in Canada are exposed more heavily to unhealthy than to healthy outlets in their residential neighbourhood. Similar trends are observed in Montreal for the non-residential foodscape. In view of our findings that relative densities of healthy and unhealthy outlets around home may shape dietary behaviours, the Canadian foodscape appears not health-promoting. Legislation on urban land use may offer ways to create more balanced environments, and thereby improve the diet of all Canadians.

6.4. Limitations of the present research

Our findings need to be considered in light of certain limitations, pertaining both to the way the foodscape was defined and operationalised, to how foodscape exposure was assessed, and to study design.

6.4.1. Limitations on the way the foodscape was defined and operationalised

We have not considered exhaustively all the places that provide food in urban environments. First, we have overlooked non-commercial resources, like community gardens (Irvine, Johnson et al. 1999), to which individuals may be exposed on a daily basis. Since these places are marginal in the urban landscape, we believe that ignoring them did not substantially bias the measure of exposure. For instance, Baker notes that in 2004, 110 community gardens have been referenced in the Greater Toronto Area (Baker 2004). This is in marked contrast with the 6 097 food outlets that are referenced in the DMTI file for the same area in 2010. In a similar vein, Reid reports that 1.5% of the population of Montreal gardens in one of the 97 community gardens (Reid 2009). Again, this number is little compared to the 6 630 food outlets that are listed in the 2010 DMTI file for Montréal. In addition, we did not account for institutional settings, such as workplace canteens (Black, Moon et al. 2014). Finally, the SIC code- and name-based assignment method used to categorize food outlets does not consider how much fruit and vegetable options are *actually* offered. Some outlets, such as full-service restaurants and cafes, were ignored, because literature does not clearly classify them as either a good or a bad source of fruit and vegetable (that is, with our wording, a healthy or an unhealthy outlet, respectively). Yet, they represent a non-negligible component of the foodscape. As a consequence, overall foodscape exposure has been underestimated.

6.4.2. Issues pertaining to residential and non-residential exposure assessment

In our conceptual proposal, we have defined foodscape exposure as "the food outlets with which individuals coexist at some point in space and time". In an attempt to address the residential trap (Chaix 2009), we have further argued in favour of considering the possible independent effects of residential and non-residential exposures on fruit and vegetable intake. Strictly assessing residential and non-residential exposures would have implied two things. First, to dispose of full and comprehensive data on both participants and outlet locations in space and time, at any moment of participant's life. Second, to be ensured that individuals actually operate a physical distinction between residential and non-residential environments, and to precisely map the boundary between these two environments. Yet, the only information available to us regarding Canadian spatial behaviours was, on one hand, the place of residence of the population under study (CCHS-participants) and, on the other hand, the places visited (including home) the day prior to the interview for a sample of Montreal's population (OD-participants) sharing similar characteristics to CCHS-participants. We have therefore built on a few assumptions to derive, from these data, proxies of residential and non-residential exposures. Doing so, we are aware that we have certainly introduced certain bias, outlined as follow.

First, we have conceptualised residential and non-residential environments as distinctive entities that may shape dietary behaviours independently from each other. Yet, individuals may not conceptualise the environment where they live and the one where they carry their activities as mutually exclusive. For instance, an individual who undertakes all its daily activities in the close vicinity of home may not operate such a distinction. Moreover, in absence of information on how participants delineate the spatial boundaries of their residential and non-residential environments, we have operated a distinction between these environments based on the *nature* of the visited places (home versus all other activity places), not on their *location*. As a consequence, a risk of overlap between both environments is to be expected in the likely eventuality of activities being carried out nearby home. On average, individuals' self-reported destinations were 8km away from home for women and 10km away from home for men. As a consequence, we may expect overlaps to be relatively limited. Yet, a qualitative assessment of how individuals distinguish their residential and non-residential environments (if they do so) would be timely.

Second, we have used adaptive kernel density estimations (KDE) to derive exposure measures at activity places (home and other declared visited places). This was based on the consideration that people bypass the spatial boundaries traditionally used to derive local exposure measures (e.g. 0.5 miles home-centered or work-centered buffers) in order to reach certain types of food outlet sparsely distributed like supermarkets. Yet, allowing the boundary of the residential and non-residential environments to fluctuate depending on the distribution of the food resources surrounding home and the other activity places may not strictly reflect foodscape exposures in the residential and non-residential areas, respectively. As a consequence, exposure may have been underestimated.

Finally, we have used values of non-residential exposure and a set of individual, household and environmental variables from the participants to the OD survey to impute non-residential exposure values for the CCHS-participants (for whom no mobility data was available), using multiple imputations. Because OD- and CCHS-populations, although sharing similar characteristics, were not the same, inferred values may slightly depart from values that would have been inferred from a strictly similar population. More importantly, because the dependent variable (fruit and vegetable intake) was not included in the Multiple Imputation models (not being available for OD-participants), the imputed values of foodscape exposure for CCHS-participants may not have the same relationship to the variable 'fruit and vegetable intake' as the observed values would do. Artificial reduction of the strength of the relationship between FVI and foodscape exposure may be expected and explain the absence of significant association in our findings. A dataset with all the necessary attributes would be needed to demonstrate that one can reliably use sample characteristics and environmental data from a distinct groups of people for imputation of non-residential exposures.

6.4.3. Issues pertaining to the study design

As raised earlier in the discussion, the cross-sectional nature of our quantitative data cannot rule out that the relative densities of healthy and unhealthy outlets around home may relate to fruit and vegetable intakes simply because individuals selectively migrate to specific environments, or because they modify their local environment through their purchasing behaviours. We have earlier argued against the former possibility. As for the latter, we have built our conceptual argumentation on the idea that individuals, through their dietary behaviours, modify their environment and get, in turn, influenced by it. The reciprocal influence of foodscape and individuals renders it difficult to isolate and actually measure the specific effect of the foodscape on dietary behaviours. Some understanding would certainly be gained from longitudinal designs, including natural experiments (Petticrew, Cummins et al. 2005). Such approaches, however, face many challenges, including difficulties to achieve satisfactory control (Cummins, Petticrew et al. 2005; Petticrew, Cummins et al. 2005), to get the required level of cooperation from the retail sector (Petticrew, Cummins et al. 2005), and to get a sufficiently high response rate from the targeted population (Cummins, Petticrew et al. 2005; Wang, MacLeod et al. 2007; Cummins, Flint et al. 2014).

Finally, all individual and household data were self-reported, with the inherent risk of over-reported bias for variables whose increased values are associated to social desirability, like fruit and vegetable consumption (Miller, Abdel-Maksoud et al. 2008).

CHAPTER 7. CONCLUSION

Over the last decades, food production has risen and food prices dropped. Although, for some people, food insecurity remains a major issue urgently needing intervention, a large population of industrialised countries has gained secure access to food. Yet, nourished populations do not mean nutritionally healthy populations. Facilitated access to food has been accompanied with a drastic increase in the occurrence of a whole range of nutrition-related chronic diseases. Despite the social and financial emergency of the situation, a general lack of understanding of the contextual determinants of (un)healthy diets in situations of food abundance has prevented governments to tackle the epidemic.

This doctoral thesis has put forward a conceptual proposal going beyond the classical approach for modeling access to food and its relation to dietary behaviours. This proposal recognises food both as a biological requirement for life, and as intimately connected to individual and social identities, hence emphasizing the complexity that surrounds the decision as to where and what to purchase over time. Notably, this proposal suggests that the relative distributions of healthy and unhealthy outlets may signal outlets popularity and steer decisions as to where to buy and what to eat. Although the two case studies further presented in this thesis do not strictly permit to validate this conceptual position, they consistently demonstrate a fundamental interdependence between the relative densities of healthy and unhealthy food outlets around home and dietary behaviours.

By providing evidence of a link between the built environment and human behaviours, this proposal stands behind the health promotion principles outlined in the Ottawa Charter for Health Promotion (Wang, MacLeod et al. 2007) that appeals to act both on individuals *and* their environments for improving populations' health. Doing so, it invites us to step away from making individuals the only practical levers for action regarding (un)healthy eating, and to better consider the currently little explored ways foodscape alteration may help tackle unhealthy dietary behaviours.

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APPENDIX I

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Field validation of secondary data sources: a novel measure of *representativity* applied to a Canadian food outlet database

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Abstract

Background: Validation studies of secondary datasets used to characterize neighborhood food businesses generally evaluate how accurately the database represents the true situation on the ground. Depending on the research objectives, the characterization of the business environment may tolerate some inaccuracies (e.g. minor imprecisions in location or errors in business names). Furthermore, if the number of false negatives (FNs) and false positives (FPs) is balanced within a given area, one could argue that the database still provides a "fair" representation of existing resources in this area. Yet, *traditional* validation measures do not relax matching criteria, and treat FNs and FPs independently. Through the field validation of food businesses found in a Canadian database, this paper proposes alternative criteria for validity.

Methods: Field validation of the 2010 Enhanced Points of Interest (EPOI) database (DMTI Spatial®) was performed in 2011 in 12 census tracts (CTs) in Montreal, Canada. Some 410 food outlets were extracted from the database and 484 were observed in the field. First, *traditional* measures of sensitivity and positive predictive value (PPV) accounting for every single mismatch between the field and the database were computed. Second, *relaxed* measures of sensitivity and PPV that tolerate mismatches in business names or slight imprecisions in location were assessed. A novel measure of *representativity* that further allows for compensation between FNs and FPs within the same business category and area was proposed. *Representativity* was computed at CT level as ((TPs +|FPs-FNs|)/(TPs+FNs)), with TPs meaning true positives, and |FPs-FNs| being the absolute value of the difference between the number of FNs and the number of FPs within each outlet category.

Results: The EPOI database had a "moderate" capacity to detect an outlet present in the field (sensitivity: 54.5%) or to list only the outlets that actually existed in the field (PPV: 64.4%). *Relaxed* measures of sensitivity and PPV were respectively 65.5% and 77.3%. The *representativity* of the EPOI database was 77.7%.

Conclusions: The novel measure of *representativity* might serve as an alternative to *traditional* validity measures, and could be more appropriate in certain situations, depending on the nature and scale of the research question.

Keywords: Field validation, Food environment, Secondary database, Sensitivity, Positive predictive value, *Representativity*

Background

Many studies have been performed to better understand the relationship between exposure to the foodscape – defined by Winson as "the multiplicity of sites where food is displayed for purchase and where it may also be consumed" [1] – and nutrition-related outcomes (e.g. obesity or dietary intakes) [2]. For pragmatic reasons, secondary data sources listing food outlets rather than field observations have been used to assess characteristics of the foodscape [3]. Uncertainty about the validity of such data sources raises the issue of potential and possibly systematic errors of measurement [4,5]. Recently, work has been conducted to validate commercial [6-9], Internet-derived [7,10] or government [8,10-12] databases, mainly in the US, the UK and Canada. Based on the match between database and field observation in "business name",

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"category" or "location", validity has traditionally been assessed using measures of sensitivity and positive predictive value (PPV), based on true positives (TPs), false positives (FPs) and false negatives (FNs). Variations in these metrics have been assessed over time [11], and in relation to neighborhood socioeconomic status [7,8,11,13,14], outlet type [6,13] or level of urbanization [8,13,14].

Criteria for validity are linked in some way to research objectives. For example, many studies have aimed to assess whether exposure - or access - to different types of food outlets influences nutrition-related outcomes [2]. Therefore, a database needs to provide a fair representation of the foodscape, i.e. an adequate evaluation of the number, type and localization of outlets. However, some slight differences between the database and reality may actually be very acceptable and have no impact on measures of foodscape exposure. For example, an error in the name of a business, when location and classification are correct, could be acceptable, since names of outlets are generally of secondary importance in studies that focus on foodscape influences. Similarly, if exposure is measured in terms of density (e.g. within a residential CT [15-18], home-centered buffer [19-21], or using kernel-density estimates [22]), a short distance between recorded and true locations should have little impact on the measure of exposure. This is particularly true if the "misplaced" outlet remains within the spatial unit in which density is computed. Furthermore, false positives (FPs) may be considered candidates for compensation for false negatives (FNs). For instance, if a database misses 10 outlets in a category in a given CT – 10 FNs - but at the same time lists 12 other outlets in the same category that are not present in the CT – 12 FPs - one can say that the database "overestimates" the number of outlets by only two. Yet, *traditional* measures of sensitivity and PPV apply distinctively to FPs and FNs and consider every single mismatch due to business name and location error. Such measures may underestimate the appropriateness of a database, for example when assessing foodscape exposure in terms of density within a specific area.

The present paper proposes a set of alternative validation measures for business listings while assessing the validity for research on the foodscape of the Enhanced Points of Interest (EPOI) file. EPOI is a Canadian database distributed by DMTI Spatial® (www.dmtispatial.com), containing over 1.6 million records of businesses. Validation was performed on food outlets listed in EPOI files within 12 CTs in Montreal. To our knowledge, no quantified validation study has been devoted to this sub-dataset, beyond minor reports of inconsistencies, missing data, or misclassifications [23].

In addition to *traditional* measures of sensitivity and PPV, we propose *relaxed* measures that tolerate mismatches in outlet names and within CT location errors. Furthermore, we introduce a novel measure of r*epresentativity* that allows for compensation between FPs and FNs within a given outlet category and CT. Variations in these measures are explored in relation to CT characteristics and outlet types.

Methods

Study area

Montreal (Island), Canada, is divided into 515 census tracts (CTs), each one covering an average surface of 0.9 km^2 [min: 0.04 km^2 – max 28.80 km^2] and containing an average of 16.1 food outlets [min: 0 – max: 637]. Building on a previous validation project performed on a different database [7], the field validation occurred within 12 CTs in Montreal. Six CTs were predominantly French-speaking and six predominantly English-speaking. Within each language group, two CTs were sampled from each socioeconomic tertile (low, medium, high). Details about the CT sampling have been published elsewhere [7].

Data sources

The list of food outlets was extracted from the EPOI dataset distributed by DMTI Spatial® and updated in 2010 (www.dmtispatial.com). For each listed outlet, the database provides a name, a postal address, a geographic coordinate, and between one and six Standard Industrial Classification (SIC) codes (four characters long), assigned to a business based on the economic activities it declares [24]. SIC codes are increasingly being replaced by the North American Industry Classification System (NAICS), which provides more specific codes (http://www.census.gov/eos/www/naics/), but is not available in this database.

Classification of food outlets

We defined 11 categories of food outlets, eight of which were food stores - mega-markets, chain supermarkets, grocery stores, convenience stores, bakery shops, fruit and vegetable stores, specialty markets (e.g. butcher or cheese shops), natural food stores - and three food services - fast-food restaurants, full-service restaurants and cafés. Establishments that were primarily bars, liquor stores or caterers were not retained. SIC codes offer a rough classification, some codes encompassing quite different types of outlets (e.g. SIC code "5411" includes mega-markets, chain supermarkets, and grocery stores as well as convenience stores). To assign food outlets to a given category, categorization was based on a SIC code- and name-based assignment method, relying upon the researcher's knowledge of the local food environment. Details on this method are shown in Additional file [see Additional file 1]. In short, we first extracted all outlets engaged in the retail of foods (SIC codes "5411 – grocery stores"; "5421 – meat and fish markets"; "5431 – fruit and vegetable markets";

"5441 – candy, nuts and confectionary stores"; "5451 – dairy product stores"; "5461 – retail bakeries"; and "5499 – miscellaneous food stores"), as well as eating places (SIC code "5812") and drinking places (SIC code "5813"). Second, outlet categories were identified using both requests on SIC code and keyword requests on business name. For instance, convenience stores were outlets with a SIC code starting with "54" and a business name having at least one keyword alluding to this outlet category (e.g. "convenience", "convenient", "gas station", etc.), including brand name (e.g. "Bonisoir", "Couche-Tard", etc.). Similarly, chain supermarkets were identified as outlets with a SIC code starting with "54" and having a supermarket brand business name (e.g. "Provigo", "Metro", "IGA", etc.). Because an outlet can declare up to six SIC codes to portray its overall activities, it could potentially have been included in more than one category. To avoid such duplicate affiliations, outlets were not made available to another category once extracted. For example, an outlet called "Provigo" declaring SIC codes "5411" (grocery), "5461" (dairy products), "5431" (fruit and vegetable) and "5421" (fish and meat) was assigned to the "chain supermarkets" category and not made available to any other categories such as "fruit and vegetable stores" or "specialty market". After identifying all outlets that came under one of the 11 defined categories, those located within the 12 targeted CTs were retained for field validation. The resulting list of outlets was reviewed, and duplicate entries based on both names and street addresses were removed. Records displaying strictly identical street addresses but names that differed only due to an additional reference to an administrative function (e.g. "office", "fax") were considered duplicates.

Field validation

One observer undertook field validation on foot in the daytime over a two-week period in October 2011, following a one-day training period during which the observer's recordings were verified using a testing CT. Supplied with EPOI lists for the 12 CTs, this person identified unlisted businesses found in the field and listed food stores trading under a different name, at a different address, or falling into a different category. An additional file shows the classification rules used to categorize observed food outlets [see Additional file 2]. Outlets that appeared to be closed permanently were not considered to be present in the field. Outlets found in the field but not listed in the database were manually searched in the whole EPOI database, using the business name and street address. This allowed further identification of FNs that would be listed in the EPOI but incorrectly geocoded outside of the selected CT. Such observations were classified as "ill-extracted", i.e. present in the whole database under the right name and street address, but wrongly geocoded. Inversely, the address and geographic coordinates of FPs were checked to ensure that the outlet had not been "inappropriately included" due to geocoding errors.

Data analysis

Firstly, the overall validity of the EPOI database was quantified through *traditional* measures of sensitivity and PPV, while considering errors in "name", "location" or "categorization" as mismatches (cf. Table 1). Second, *relaxed* measures of sensitivity and PPV were computed. These ignored mismatches due to a difference in outlet name or to a within-CT inaccuracy in location (e.g. listed outlet with wrong address but correctly in the CT). Third, a novel measure of *representativity* was proposed as follows:

$$Representativity = \left((\mathbf{TPs}+|\mathbf{FPs}-\mathbf{FNs}|) / (\mathbf{TPs}+\mathbf{FNs}) \right)$$

with TPs meaning true positives, and |FPs-FNs| being the absolute value of the difference between the number of FNs and the number of FPs within each outlet category.

Measures of sensitivity, PPV and *representativity* were computed for each of the 12 CTs. Overall values for these metrics were computed as the average of all CT-level measures, weighted by the number of outlets per CT. Measures below 0.30 were considered as "poor", from 0.31–0.50 as "fair", from 0.51–0.70 as "moderate", from 0.71–0.90 as "good", and over 0.90 as "excellent". Such a scale is only provided for indicative purposes, as terminology can be debatable (e.g. "good", with a value of 0.71, fails to identify an existing outlet or identifies a non-existent one about one-third of the time). These descriptors were adopted, however, for the purpose of more easily comparing results with the existing literature [7,10]. Pearson's chi-square tests of independence performed with SPSS were used to assess variations in sensitivity and PPV in relation to CT socioeconomic status ("low", "medium", "high"), CT language ("French", "English") and outlet category. Sensitivity and PPV were displayed in contingency tables as binary variables. Sensitivity was said to be "not encountered" when an outlet was present in the field but not on the list (false negative), and "encountered" when an outlet was both present in the field and listed (true positive). Similarly, PPV was said to be "not encountered" when an outlet was present on the list but not in the field (false positive), and "encountered" when an outlet was both present in the field and listed (true positive). In order to reach a critical size per cell, mega-markets and chain supermarkets were combined. Although the conditional Fisher's exact test (two-sided p) has been widely used to assess such variations [7,8,11,13,14], we do not recommend it. Primarily, the expected "beforehand fixed margins" condition (i.e. the row sums and the column

Table 1 Calculation of *traditional* and *relaxed* sensitivity and positive predictive value (PPV), and *representativity*

	Outlet present (field)		Outlet absent (field)	
Outlet present (database)	True positive (TP)		False positive (FP)	
	For traditional measures	*For relaxed measures/ Representativity*	*For traditional measures*	*For relaxed measures/ Representativity*
	Match with respect to any name, location and category error	Match disregarding errors in name and imprecisions in location	Includes outlets mismatched due to name errors and imprecisions in location	Excluding outlets mismatched due to name errors and imprecisions in location
Outlet absent (database)	False negative (FN)		True negative (TN)	
	For traditional measures	*For relaxed measures/ Representativity*		
	Including outlets mismatched due to name errors and imprecisions in location	Excluding outlets mismatched due to name errors and imprecisions in location		

sums are fixed prior to the study) is not encountered in observational studies [25]. In fact, the number of outlets – whether correctly listed (TPs), listed but not found in the field (FPs), or not listed but found in the field (FNs) – can only be deduced from field observations. Some have therefore suggested that this test "should practically never be used" [26].

Results

After removing 22 duplicate entries, the EPOI database provided a list of 410 outlets, of which 50.0% were full-service restaurants, 12.4% convenience stores, 9.0% cafés, 7.8% fast-food restaurants, 7.1% grocery stores, 5.1% bakeries, 3.2% specialty markets, 2.2% fruit and vegetable stores, 2.2% natural food stores, 0.7% chain supermarkets, and 0.2% mega-markets (Table 2).

The fieldwork recorded a total of 484 outlets. Of the 410 listed outlets, 264 matched perfectly with the outlets observed in the field, while 81 were mismatched, including 50 mismatched in “name”, 3 in “location”, 16 in “category” and 12 in both “name” and “category”. Some 139 outlets found in the field were not listed in the extracted list. Of these, 34 were actually present in the remaining records of the complete EPOI database. While their names, categories and street addresses were correctly documented, a geocoding error, probably associated with an error in the 6-digit postal code, had prevented their correct spatial location and corresponding extraction. Some 65 listed outlets were not found in the field. None owed their erroneous presence to geocoding errors, as their street addresses were located in the appropriate CT. However, the EPOI database shows a significant number of geocoding inaccuracies. For the entire set of Montreal food outlets (n=8300), 6.9% of outlets (n=570) had a poor geocoding precision code (i.e. geocoded at municipal centroid).

Traditional and *relaxed* measures of sensitivity and PPV

Traditional sensitivity was 54.5% (CI [48.7% - 60.3%]), and PPV 64.4% (CI [59.2% - 69.6%]), or “moderate” (Table 3). When relaxing matching criteria on “name” or “location”, sensitivity increased to 65.5% (CI [59.2% - 71.8%]) and PPV to 77.3% (CI [73.6% - 81.0%]).

Novel measure of *representativity*

Further accounting for the compensation between FNs and FPs provided a “good” *representativity* measure of 77.7%; (CI [71.3% - 84.0%]).

Variations

No significant difference was observed by CT characteristic (SES and language) for both *traditional* and *relaxed* measures. Chi-square analyses indicated no between-category differences in *traditional* sensitivity (Pearson Chi Square’s $p = 0.413$) or PPV ($p = 0.058$). Significant differences were, however, observed for *relaxed* sensitivity ($p = 0.001$) and PPV ($p = 0.000$), with higher values obtained for convenience stores, full-service restaurants, and fruit and vegetable stores compared to other outlets.

Discussion

Secondary data sources offer various options for describing foodscapes. Yet the validity of such commercial, government and Internet-derived database needs to be evaluated. This paper assessed the validity of the EPOI database in 12 CTs in Montreal, Canada. *Relaxed* measures of sensitivity and PPV were compared to *traditional* measures, and a novel measure of *representativity* was proposed. *Traditional* validity measures indicated a "moderate" capacity of the database to detect the presence of outlets in the field (sensitivity of 54.5%; CI [48.7% - 60.3%]) or list the sole outlets actually existing in the field (PPV of 64.4%; CI [59.2% - 69.6%]). No evidence of systematic

Table 2 Records in EPOI database against field observations

		No. of outlets listed	Disposition						No. of outlets found but not listed	
			Matching	Not matching				Not found		
				Error in name	Error in location	Error in category	Error in both name and category		Not present in EPOI database	Ill-extracted from EPOI database
	Total	**410**	**264**	**50**	**3**	**16**	**12**	**65**	**105**	**34**
Food stores	Convenience stores	51	37	9	1	1	1	2	13	1
	Chain supermarkets	3	3	0	0	0	0	0	1	0
	Grocery stores	29	16	0	0	6	2	5	5	4
	Bakeries	21	13	2	0	3	0	3	6	3
	Specialty markets	13	9	0	0	0	0	4	4	1
	Fruit and vegetable stores	9	5	2	0	0	0	2	1	3
	Natural food stores	9	7	0	0	1	0	1	6	2
	Megamarkets	1	1	0	0	0	0	0	0	0
Food services	Fast-food restaurants	32	25	0	1	1	2	3	11	2
	Cafés	37	18	1	1	2	3	12	19	6
	Full-service restaurants	205	130	36	0	2	4	33	39	12
Census tract predominant LANGUAGE	English	295	186	41	3	13	9	43	75	22
	French	115	78	9	0	3	3	22	30	12
Census tract SES	Low	73	51	5	2	1	0	14	22	9
	Medium	164	102	29	1	7	6	19	41	6
	HIGH	173	111	16	0	8	6	32	42	19

differences related to CT characteristics or outlet category was observed. These findings are similar to others previously reported in the literature, in the "fair" to "moderate" range [8,13], although some studies have reported sensitivity and PPV in the "good" to "excellent" range [7,11,14]. How do these results help us to reach conclusions about the appropriateness of such a database for evaluating foodscapes, however?

The question of what criteria should prevail in order to consider a database "valid" for foodscape characterization has not been much debated. Whereas in some studies any difference in “name”, “location” or “category” is considered a mismatch [8,13], others relax on certain criteria – including name, address, category, or subcategory [7,11,13]. Our findings showed that measures of sensitivity and PPV do differ quite substantially on whether or not they ignore name errors or inaccuracies in location. Estimates of sensitivity and PPV respectively increased from 54.5% and 64.4% to 65.5% and 77.3% after relaxing on those aspects. Differences in the choice of matching criteria may partly explain why some studies have concluded that secondary data sources provide a valid alternative to fieldwork [7,9,14], while others have expressed the need for caution [8,10,13].

Such discrepancies raise the issue of which criteria should be considered to assess the validity of databases for use in characterizing foodscapes. Because exposure is often measured in terms of density for a given outlet type at a given location (e.g. within the residential CT, within a home- or school-centered buffer, or using kernel estimates), discrepancies in business names or small location errors (e.g. records staying in the same spatial unit) have no impact on exposure estimates. Whether the database is an exact copy of the field may not be relevant. *Traditional* measures of validity that account for every single mismatch in business name or exact location may be too conservative and lead to misguided recommendations for use. Along these lines, FPs and FNs should not always be considered independently, but rather seen as a whole. Some have advised combining multiple data sets to reduce FNs and increase PPV [10]. Such a strategy may, however, inappropriately increase the number of FPs and decrease sensitivity [8]. The criteria that should prevail to determine whether or not an observed difference between the database and the field is acceptable should vary according to the research objectives. The proposed measure of *representativity* allows for compensation between FPs and FNs, while errors in business names or

Table 3 Validation statistics for the EPOI database

				Traditional measures				*Relaxed* measures					
	N Total	N List	N Field	Sensitivity		Positive predictive value		*Relaxed* sensitivity		*Relaxed* positive predictive value		*Representativity*	
				Est.		Est.		Est.		Est.		Est.	
Overall	549	410	484	0.545		0.644		0.655		0.773		0.777	
				0.487	0.603	0.592	0.696	0.592	0.718	0.736	0.810	0.713	0.840
Census tract characteristics													
Low SES	104	73	90	0.567		0.699		0.700		0.732		0.756	
				0.508	0.625	0.590	0.808	0.478	0.923	0.581	0.882	0.723	0.788
Medium SES	211	164	192	0.531		0.622		0.748		0.830		0.797	
				0.454	0.608	0.515	0.729	0.578	0.917	0.788	0.871	0.753	0.841
High SES	234	173	202	0.550		0.642		0.578		0.709		0.762	
				0.422	0.677	0.605	0.678	0.394	0.761	0.660	0.758	0.628	0.897
English	392	295	349	0.533		0.631		0.690		0.755		0.791	
				0.472	0.594	0.567	0.694	0.544	0.837	0.713	0.798	0.740	0.842
French	157	115	135	0.578		0.678		0.660		0.758		0.733	
				0.462	0.693	0.592	0.764	0.485	0.835	0.644	0.873	0.633	0.833
Categories of outlet													
Convenience store	65	51	63	0.587		0.725		0.746		0.922		0.762	
				0.489	0.686	0.604	0.847	0.636	0.856	0.856	0.987	0.644	0.880
Chain supermarkets	4	3	4	0.750		1.000		0.750		1.000		0.750	
				0.325	1.175	1.000	1.000	0.325	1.175	1.000	1.000	0.325	1.175
Grocery stores	38	29	33	0.485		0.552		0.485		0.552		0.545	
				0.278	0.692	0.371	0.732	0.278	0.692	0.371	0.732	0.361	0.730
Bakeries	30	21	27	0.481		0.619		0.556		0.714		0.593	
				0.289	0.674	0.428	0.810	0.320	0.791	0.512	0.916	0.338	0.847
Specialty markets	18	13	14	0.643		0.692		0.643		0.692		0.786	
				0.423	0.863	0.563	0.822	0.423	0.863	0.563	0.822	0.539	1.032
Fruit and vegetable stores	13	9	11	0.455		0.556		0.636		0.778		0.727	
				0.170	0.740	0.304	0.807	0.353	0.920	0.502	1.053	0.414	1.040
Natural food stores	17	9	16	0.438		0.778		0.438		0.778		0.500	
				0.141	0.734	0.413	1.142	0.141	0.734	0.413	1.142	0.200	0.800
Megamarkets	1	1	1	1.000		1.000		1.000		1.000		1.000	
Fast-food restaurants	45	32	42	0.595		0.781		0.619		0.813		0.690	
				0.459	0.731	0.707	0.856	0.486	0.752	0.747	0.878	0.533	0.848
Cafés	62	37	50	0.360		0.486		0.400		0.541		0.600	
				0.249	0.471	0.339	0.634	0.297	0.503	0.421	0.660	0.453	0.747
Full-service restaurants	256	205	223	0.583		0.634		0.744		0.810		0.861	
				0.522	0.644	0.581	0.687	0.690	0.799	0.770	0.850	0.809	0.913

minor location inaccuracies can be tolerated. When the dataset is used to assess densities of outlets, *representativity* offers a good complement to *traditional* validity measures. Yet, when relaxing on location and offsetting FNs with FPs, a "spatial tolerance threshold" must be set. This threshold can be of the form "must stay within a same spatial unit" or "must stay within a given distance". Consequently, *relaxed* measures of validity – allowing spatial imprecision – and *representativity* – allowing compensation between FPs and FNs – are dependent on these spatial criteria. Smaller tolerance thresholds – say, location errors of less than 100 meters, or compensation between FPs and FNs only allowed within a short distance from each other or within the same small spatial unit –

are less permissive. Measures of *representativity* should therefore always be provided along with a spatial tolerance criterion. If an exact representation of the field is needed, *relaxed* or *representativity* measures are not useful. This may be the case when databases are used to obtain exact measures of proximity (e.g. [27-29]). Therefore, we do not recommend systematic reliance on *representativity*. We believe it is an interesting metric to document how close a database is able to "represent" a true measure of exposure. The relevance and appropriateness of this *representativity* does, however, depend on the research objectives and methods used to assess exposures.

With a *representativity* of 77.7% (CI [71.3% - 84.0%]), the EPOI database represents 77.7% of the CT foodscape, which can be considered good but not excellent. Correcting the 34 geocoding errors raises *representativity* to 80.5% (CI [74.2% - 86.7%], which shows how deleterious geocoding inaccuracies can be [30], but they can also be identified and sometimes corrected. Specifically, one needs to scan such a database to assess unique coordinate frequencies and detect possible artificial clusters due to geocoding approximations. In Montreal, a large number of outlets coded at the city level would fall within a single CT, for which the density estimate is consequently extremely inaccurate. Refining geocoding constitutes an interesting avenue for improving the quality of the EPOI database.

Limitations

Firstly, because validation measures were limited to 12 CTs (i.e. 2.3% of all CTs in Montreal), cautious interpretation is required. The small size of our sample may have resulted in unstable estimates of error. Overall patterns were consistent along Montreal's urban socioeconomic and language composition, suggesting that our estimates are reasonably reliable and valid. Yet, those variations were tested based on only two CTs in each SES and language category. Therefore, the design of our study may have lacked the power to detect them. Further validation in different cities and using wider data samples would be useful to allow for generalizability. Particular caution should be expressed regarding rural areas, as our sample did not cover that type of territory.

Second, because the field validation occurred one year after the EPOI dataset was released, actual changes in the foodscape [31-33] may have affected validity measures. Outlets closing, opening, rebranding, and changes of ownership over this one-year time-lapse have presumably increased the number of FPs, FNs and mismatches in business name. This impact potentially contributed to underestimating both *traditional* and *relaxed* measures of validity. Since *relaxed* measures overlook mismatches in outlet name, the one-year time-lapse should, however, have a lower impact on *relaxed* than on *traditional* measures. Additionally to this quantitative aspect, the way the foodscape renewed itself over this period of time may also have qualitative implications. For instance, areas with major arrivals of new migrants may experience modifications in the nature of the food offer (e.g. closing of six convenience stores and opening of nine specialty outlets or ethnic stores over the same time period). Inversely, in areas with a stable socio-demographic structure, the food offer may stay roughly the same (e.g. closing of six convenience stores followed by the opening of five new convenience stores). In the former case, the possibility of compensation is null, while in the latter, five compensations for FPs by FNs are made possible. However, since we know little about foodscape dynamics over the one-year time-lapse that separates the EPOI database release from field validation, we cannot say how much this period of time has specifically affected *representativity*.

Third, since some head offices operate under a different name than the attached retail outlet, some of the duplicate entries we aimed at removing may have been overlooked. If such head offices had been purged back, the performance of the EPOI database could have been improved.

Finally, the method we chose to categorize outlets may have led to some misclassifications. The name-based assignment method used to compensate for low-specific SIC codes may have failed to assign some outlets to the correct category, or the observer may have assigned the wrong category to a given outlet observed in the field. Despite some attempts [10,34], no precise criteria were agreed upon for rigorously and systematically assigning an outlet to a given category. We proposed a name-based assignment method to refine the EPOI database categorization, and the observer was equipped with a classification tool that helped categorize outlets based on the type, nutritional quality and specificity of their offerings, as well as the size of the premises [see Additional File 2]. However, the wide-ranging activity of some outlets (e.g. restaurants that also offer take-out food, or supermarkets that have counters with food for on-site consumption), may have made exclusive classification difficult. Along these lines, as most outlets sell both healthy and unhealthy options, though in different proportions, the right assignment is made difficult (e.g. distinction between convenience and grocery stores).

Because the observer was not blinded to the EPOI list during field validation, he may have been tempted to adopt the EPOI list's categorization when the assignment of an outlet to a single category based on field observation was difficult. Therefore, the number of category errors identified (n=16 out of 410 outlets listed) might have been underestimated, and validity measures overestimated. Further research should provide better guidelines for classifying food outlets. Such criteria should guide correspondence between commercial classifications of outlets as they appear in secondary data sources, and classifications according to the nutritional behavior they promote. The multiple nature of some outlets (e.g. with both food for on-site consumption and take-out food, or with both healthy and unhealthy offerings) remains a challenge for assessing exposure.

Conclusions

It is important to assess the validity of secondary databases used to characterize foodscapes in order to obtain valid estimates of exposure and reduce bias. The proposed measures of *relaxed* sensitivity and PPV, and particularly the novel measure of *representativity*, offer interesting alternatives to *traditional* measures of validity. The EPOI database had a poor capacity to detect the exact outlets in the field. However, relaxing on outlet names and allowing small location imprecisions improves its performance. Furthermore, when compensation between FPs and FNs was allowed within CTs, the EPOI database offered good *representativity* of the CT foodscape. The EPOI database can consequently be considered as inadequate for measuring exact distance to specific outlets, but it is a valuable resource for assessing local densities. Therefore, it is not so much which of *traditional* or *relaxed* measures are "superior", as under what circumstances the use of *relaxed* and *representativity* measures may be more appropriate.

Additional files

Additional file 1: SIC codes- and name-based assignment method used to categorize food outlets.

Additional file 2: Classification tool aiming at facilitating categorization of food outlets found on-site.

Abbreviations

CT: Census tract; EPOI: Enhanced Points of Interest; FNs: False negatives; FPs: False positives; NAICS: North American Industry Classification System; PPV: Positive predictive value; SES: Socioeconomic status; SIC: Standard Industrial Classification; TNs: True negatives; TPs: True positives.

Competing interests

Christelle M Clary has no financial disclosure. Yan Kestens has no financial disclosure.

Authors' contributions

CC carried out the field validation study, organized the one-day training period for the field observer, performed the statistical analyses and drafted the manuscript. YK participated in the design of the study, contributed to the statistical analyses and revised the manuscript. Both authors approved the final manuscript.

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APPENDIX II

Title: The local food environment and fruit and vegetable intake: a Geographically Weighted Regression approach in The ORiEL Study

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Abbreviations: AICc, Akaike Information Criterion corrected; GWR, geographically weighted regression; ORiEL, Olympic Regeneration in East London.

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ABSTRACT

Studies that explore associations between the residential food environment and diet routinely use global regression models which assume that relationships are invariant across space. However this approach may fail to detect important local environmental effects. Here we used global and geographically weighted regression (GWR) models to explore associations between the residential food environment and fruit and vegetable intake among 969 adults in The ORiEL Study. Exposures were assessed both as absolute densities of healthy and unhealthy outlets taken separately, and as a relative measure as the percentage of healthy outlets. Findings from global models showed positive association between the relative measure and fruit (β=0.022, $P < 0.01$) and vegetable (β=0.021, $P < 0.01$) intake only. GWR models showed that regression estimates varied across space, although to a lesser extent for relative measures compared to absolute measures. Overall, spatial models performed better than global models (decreased AICc; and suppression of spatial autocorrelation in standardised residuals). This study challenges the commonly held assumption that relationships between the local food environment and diet are invariant across space. Regression estimates are more stationary for relative rather than absolute measures, suggesting that spatial heterogeneity could be mitigated by choice of exposure measure.

Keywords: fruit and vegetable intake; geographically weighted regression; local food environment; non-stationarity; relative and absolute exposures

Over the last decade, an extensive body of research has investigated how the local food environment may be related to dietary behaviours (Kamphuis, Giskes et al. 2006). A large majority of studies have used global regression to model the association between exposure to either healthy or unhealthy food environments and diet-related outcomes (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012). Reviews have however highlighted the lack of consistency in findings (Charreire, Casey et al. 2010; Caspi, Sorensen et al. 2012), with associations being either positive (Laraia, Siega-Riz et al. 2004; Rose and Richards 2004; Satia, Galanko et al. 2004; Zenk, Schulz et al. 2005; Bodor, Rose et al. 2008; Moore, Diez Roux et al. 2009; Zenk, Lachance et al. 2009), negative (Asfaw 2008), or non-existent (Cummins, Petticrew et al. 2005; Jeffery, Baxter et al. 2006; Pearce, Hiscock et al. 2008; Pearce, Hiscock et al. 2009; Macdonald, Ellaway et al. 2011; Zenk, Schulz et al. 2011; Flint, Cummins et al. 2012).

By using global regression models, researchers have implicitly relied on the assumption of a *stationary* relationship, that is, parameter estimates describe what is assumed to be an invariant relationship across space. However, public health researchers have begun to challenge the stationarity assumption. Using spatial regression modeling, such as geographically weighted regressions (GWR), a technique that captures spatial variations in parameters estimates (Fotheringham, Charlton et al. 1998; Fotheringham, Brunsdon et al. 2002), they have highlighted variation in associations across space between a range of environmental exposures and outcomes such as diet (Fraser, Clarke et al. 2012), obesity (Procter, Clarke et al. 2008; Chen and Truong 2012; Chalkias, Papadopoulos et al. 2013; Chi, Grigsby-Toussaint et al. 2013; Black 2014; Xu and Wang 2015), active transportation (Feuillet, Charreire et al. 2015), and birth weight (Tu, Tu et al. 2012). Fraser et al. have observed marked spatial variations, both in magnitude and nature, in the relationship between fast-food residential exposure and consumption among adolescents living in Bristol, UK (Fraser, Clarke et al. 2012). Higher exposure was significantly associated with increased consumption in some areas, but decreased consumption in others, even after adjusting for deprivation, gender, and physical activity levels. Overall, local modelling, when compared to global modeling, has shown better performance in terms of, improved goodness-of-fit (Chen and Truong 2012; Chi, Grigsby-Toussaint et al. 2013; Feuillet, Charreire et al. 2015; Xu and Wang 2015), increased R^2 (Chen and Truong 2012; Chalkias, Papadopoulos et al. 2013; Chi, Grigsby-Toussaint et al. 2013; Feuillet, Charreire et al. 2015; Xu and Wang 2015), and decreased spatial autocorrelation in regression residuals (Chen and Truong 2012; Chalkias, Papadopoulos et al. 2013; Chi, Grigsby-Toussaint et al. 2013; Xu and Wang 2015)). Where non-stationarity has been pointed out, authors have therefore raised a caveat associated with the use of global models (Nakaya, Fotheringham et al. 2005; Chi, Grigsby-Toussaint et al. 2013).

Demonstrations of how a more spatially explicit approach to modelling might improve the understanding of associations between the food environment and diet is limited, however. To address this gap, this paper uses GWR models, alongside 'classical' global models, to predict fruit and vegetable intakes in relation to the residential food environment. Recent literature has suggested that relative measures, that account simultaneously for both healthy and unhealthy exposures, may be better correlates of diet than the traditional absolute measures, that account for either healthy or unhealthy outlets alone (Mason, Bentley et al. 2013; Clary, Ramos et al. 2015). Therefore, residential exposure was assessed both as absolute densities of healthy and unhealthy outlets, taken separately, and as a relative measure as the percentage of healthy outlets.

METHODS

Data

Individual data. Adult socio-demographic and behavioural data were drawn from The ORiEL (Olympic Regeneration in East London) Study, a school-based longitudinal controlled quasi-experimental study in four boroughs of East London evaluating the health and social legacy of the London 2012 Olympics (Smith, Clark et al. 2012). For the purposes of the current study baseline cross-sectional data, collected between April and July 2012, on the parents of the adolescents in the surveyed schools were utilised (n=1277). Data were collected via computer assisted personal interviews with a response rate of 60%.

Food environment data. Data on the local food environment was collected from each of the four study boroughs, and in two coterminous boroughs in order to mitigate edge effects where the boundaries between study and non-study boroughs were most likely to be crossed by participants (Figure 1). It was assumed that the River Thames which bounds the southern study area acts as a natural barrier, and hence we did not collect data south of the river. Secondary data on the location of food businesses was obtained from the public register of food premises for each borough. The collection of these data is a mandatory requirement under UK food safety legislation and are a high quality resource for research purposes (Lake, Burgoine et al. 2010). 7,927 food outlets were geocoded to address-level using the Ordnance Survey MasterMap Address Layer 2 product (Cummins and Macintyre 2009; OrdnanceSurvey® 2011). A sample was validated against concurrent Google Maps Streetview and Bing Maps Streetside data returning high positive predictive values indicative of reliable data (unpublished results). Finally, food businesses were classified according to a mutually exclusive classification informed by the literature (Web Appendix 1). Food outlets' categories were further classed as either healthy or unhealthy, based on the range of fresh, frozen and canned fruits and vegetables it routinely provides (Sallis, Nader et al. 1986; Rose and Richards 2004). The former encompassed chain supermarkets, independent supermarkets, fruit and vegetable shops, and ethnic-specific supermarkets; and the latter convenience stores, fast-food chains, and independent fast-food. The other listed outlet classes were not retained, as their affiliation to either healthy or unhealthy categories has not been established in the literature.

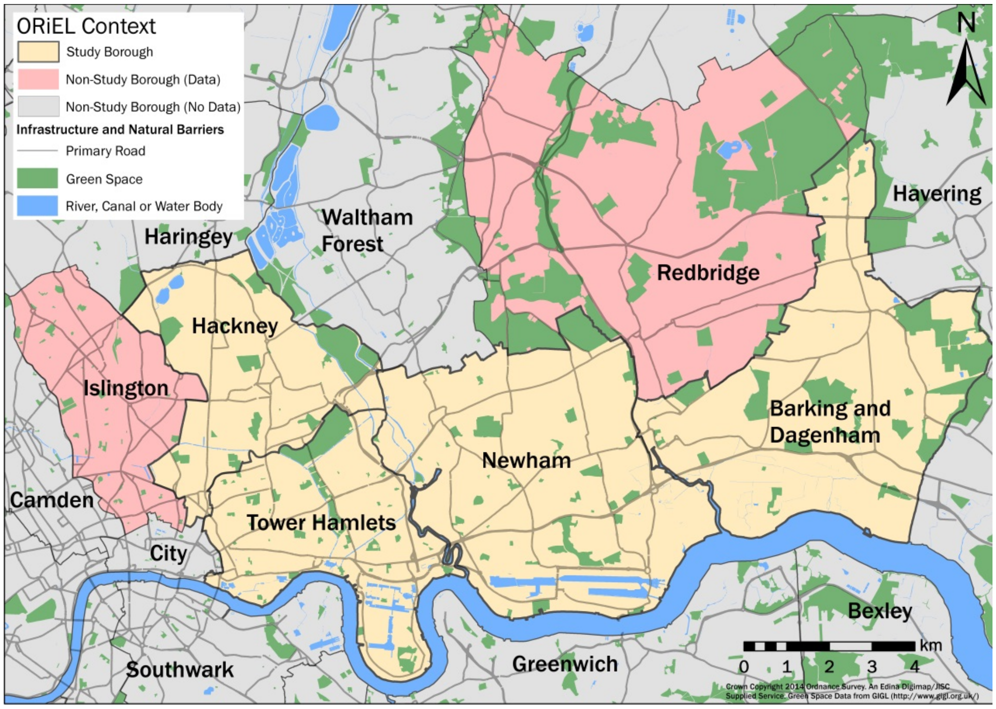

Figure 1. Map of the ORiEL and food environment data collection, London, United-Kingdom, 2012

Variables

Fruit and vegetable intake. Building on the Health Survey for England (http://data.gov.uk/dataset/health_survey_for_england), participants were asked two questions about their average daily portions - or handful size amount - of fruit and vegetable intake. Response categories were: “none”, “one”, “two”, “three”, “four”, and “five or more”. Fruits included fresh, frozen, canned and dried fruits, as well as fruit juices. Vegetables (excluding potatoes) encompassed fresh, frozen and canned vegetables. Fruit intake and vegetable intake were examined separately since previous research has found that the food environment may impact their intake differently (Kamphuis, Giskes et al. 2006; Bodor, Rose et al. 2008).

Food environment exposure. Kernel Density Estimations were computed in Crimestat (Levine 2005) for each of the seven food outlets categories retained. Kernel Density Estimation is an interpolation technique that transforms discrete spatial data into continuous density estimations based on a kernel of particular bandwidth and symmetrical density function (Silverman 1986). The surface value is highest at the location of the observation point (i.e. food outlet location) and diminishes with increasing distance from this point, reaching its lowest value (e.g. zero for a quartic kernel) at the search radius (bandwidth) distance. The bandwidth can be fixed so that the distance from the observation point is either constant (*fixed* kernel density), or varies to maintain the number of observations under the curve constant (*adaptive* kernel density). The output is a raster file, with density estimates provided at each raster cell center, by adding the values of all kernel surfaces.

Density estimates were computed for raster cells of a 30 meter size, with a quartic function and an adaptive bandwidth using 7% of the nearest observations (Web Appendix 1). It has been shown that individuals often bypass their immediate environment to undertake major food shopping trips in large retailers located outside of their immediate neighbourhood (Day 1973; Hillier, Cannuscio et al. 2011; Drewnowski, Aggarwal et al. 2012; Kerr, Frank et al. 2012; LeDoux and Vojnovic 2013). but still shop locally for top-up and convenience food (LeDoux and Vojnovic 2013). Food environment exposure measures should therefore be allowed to vary according to food outlet type and density. Using an adaptive bandwidth is therefore conceptually more appropriate than using a fixed environmental exposure (such as a network buffer). Several sizes of adaptive bandwidth were tested: 1%, 3%, 5%, 7%, and 10% of the nearest observations. The 7% bandwidth was retained as the magnitude of the association with fruit intake and vegetable was the greatest (Web Appendix 2). Density values for each category of food outlets were extracted at participants' addresses, using the spatial analyst tools in ArcGIS 10.1.

Two absolute and one relative density-based measures of food environment exposure were computed at the address-level. Absolute exposure to healthy outlets was obtained by summing the densities of fruit and vegetable shops and chain, independent, and ethnic-specific supermarkets. Absolute exposure to unhealthy outlets was computed by summing the densities of convenience stores, fast-food chains, and independent fast-food restaurants. The proportion of healthy outlets was derived by dividing absolute exposure to healthy outlets by the sum of densities of all outlets.

Socio-demographic data. The following variables were considered as potential confounders of the relationship between the food environment and fruit and vegetable intake: age [continuous]; sex [female/male]; marital status [married, single, divorced/separated/widowed]; ethnic origin [White British/Irish, Asian/Asian British, Black/Black British, other]; highest qualification based on National Vocational Qualification level [none, low, intermediate, high, foreign]; and neighbourhood deprivation [low, medium-low, medium-high, high] based on the "income deprivation" score of the 2010 Index of Multiple Deprivation (DCLG 2011) available for every Lower Layer Super Output Area (LSOA) in England. We extracted score values at participants' postcode using ArcGIS v10.1., and transformed the resulting variable in quartiles. Because time spent at home may confound how the food environment relates to fruit and vegetable intake (Chum, Farrell et al. 2015), we computed a proxy for time spent in the neighbourhood variable, termed time-budget [low, intermediate, high, other], derived from employment status and working hours. We considered time-budget to be inversely proportional to the time individuals reported spending in constrained activities, including work, studying and looking after the home or family members. Individuals working more than 30 hours a week were categorised as having a 'low' time budget; those working between 30 and 12 hours a week, being students, or looking after home or family were classified in the "intermediate" group. Finally, those working less than 12 hours a week, or being retired, or unemployed were considered having a 'high' time budget. An additional category - "other" - encompassed people with long-term sickness or disability, on maternity leave, on holiday or temporarily laid off, and individuals who declared another employment status.

Statistical analyses

First, fruit intake and vegetable intake were modelled separately using global linear regression (OLS) in SPSS v.20, with the three density measures used as the exposure variable in separate models. All six resulting models were fully adjusted for the following potential confounders: age, sex, marital status, qualification, ethnicity, time-budget, and neighbourhood deprivation. Because previous studies have found gender differences in the relationship between food environment exposure and dietary intake (Wang, Kim et al. 2007; Macdonald, Ellaway et al. 2011; Kestens, Lebel et al. 2012; Lebel, Kestens et al. 2012), the interactions between sex and exposure were included in preliminary analyses, but excluded from each of the six models since they were not significant (p-values ranged from 0.141 to 0.972).

Second, spatial regressions (GWR) were performed with GWR4.0 software (Nakaya 2012), in order to account for the possible spatial non-stationarity of these relationships. Rather than calculating global parameter estimates based on one regression, GWR performs a series of local regressions with coefficients varying conditional on the location (i.e. participant address), drawing on the weighted surrounding data points (Fotheringham, Brunsdon et al. 2002). Only the β-coefficients of exposure to the food environment were allowed to locally vary over space, while the terms for other explanatory variables were fixed (semi-parametric GWR). We used a kernel with an adaptive Gaussian function, and the bandwidth minimizing the corrected Akaike Information Criterion (AICc). The local β-coefficients of the six relationships under study, as well as the corresponding t-values, were mapped with ArcGIS 10.1 using Inverse Distance Weighted interpolations.

Third, AICc values, reported for both global regression and GWR models, were used to compare models' performance (Johnson and Omland 2004). The model with the lower AICc was taken as having a better fıt. A difference in AICc of more than 3 values was regarded as a notable difference between two models (Fotheringham, Brunsdon et al. 2002). Eventually, spatial autocorrelation of standardized residuals was checked for both global and GWR models in GeoDa, using Morans'I. The spatial relationship was conceptualised as an inverse Euclidean distance function (1000 meter-bandwidth), with row standardised spatial weights.

RESULTS

Descriptive analyses

Participants whose home was located outside of the four study boroughs (n=31), who declared they had resided for less than a year at their current address (n=73), and for whom data was missing (n=228), were removed. Out of the 1277 interview participants, a sub-sample of 969 individuals was used for the analyses. Descriptive characteristics of participants are presented in Table 1. Participants were mostly women (75.5%), married (63.8%), and had predominantly no or low qualifications (22.7% and 29.2% respectively) and an intermediate time-budget (54.6%). The study sample was ethnically diverse with the largest group being "Asian/Asian British" (33.3%), followed by "White British/Irish" (25.0%), "Black/Black British" (22.5%) and "Other White Background" (13.8%). Three-quarters (74.6%) of participants declared eating two or more portions of fruits a day, 42.3% reported consuming three or more portions of vegetables, and 51.6% attained the recommended intake of five or more portions of fruits and vegetables (2006).

Table 1. Socio-demographic Characteristics and Fruit and Vegetable Intakes of Individuals (n=969), Baseline of the Olympic Regeneration in East London (ORiEL) Study, London, United-Kingdom, 2012

	Total
Sociodemographic characteristics	
Age - *Mean (Std dev)*	40.25 (8.21)
Sex - *Frequency (%)*	
Female	732 (75.5)
Male	237 (24.5)
Ethnic origin - *Frequency (%)*	
White British or Irish	242 (25.0)
Other White background	134 (13.8)
Asian or Asian British	323 (33.3)
Black or Black British	218 (22.5)
Other ethnic background, including mixed background	52 (5.4)
Highest qualification level[a]- *Frequency (%)*	
None	220 (22.7)
Low	283 (29.2)
Intermediate	83 (8.6)
High	188 (19.4)
Foreign	195 (20.1)
Marital status - *Frequency (%)*	
Married or in a civil partnership	618 (63.8)
Separated, but still legally married or in a civil partnership; Divorced; Widowed	123 (12.7)
Never married or never in a civil partnership	228 (23.5)
Time-budget[a]- *Frequency (%)*	
Low time-budget	193 (19.9)
Intermediate time-budget	529 (54.6)
High time-budget	206 (21.3)
Non applicable	41 (4.2)
Food intakes	
Daily fruit consumption - *Frequency (%)*	

0 portion	70 (7.2)
1 portion	176 (18.2)
2 portions	280 (28.9)
3 portions	258 (26.6)
4 portions	112 (11.6)
5 or + portions	73 (7.5)
Daily vegetable consumption - *Frequency (%)*	
0 portion	47 (4.9)
1 portion	204 (21.1)
2 portions	308 (31.8)
3 portions	227 (23.4)
4 portions	103 (10.6)
5 or + portions	80 (8.3)
Daily fruit and vegetable consumption - *Frequency (%)*	
< 5 portions	469 (48.4)
5 or + portions	500 (51.6)

[a]*Differences between daily fruit and vegetable consumption groups significant at p<0.05*

Participants' exposure to the food environment is presented in Table 2. On average, participants were exposed to 2.65 [Min: 0.13; Max: 15.03] healthy and 16.33 [1.26; 50.66] unhealthy outlets per km². The average percentage of healthy outlets around home was 12.55% [3.32%; 37.42%]. Participants with higher exposure to healthy outlets were also more likely to also have higher exposure to unhealthy outlets (Spearman's correlation coefficient= 0.866, *P* < 0.001).

Table 2. Measures of the Food Environment Exposure at Residential Address of ORIEL Participants (n=969), London, United-Kingdom, 2012

	Mean (Std Dev)	[Min;Max]	Spearman r Value (p-value)
Absolute densities around home			
All healthy outlets (nb of healthy outlets/km²)	2.65 (2.26)	[0.13;15.03]	
All unhealthy outlets (nb of unhealthy outlets/km²)	16.33 (9.05)	[1.26;50.66]	
Relative density around home			
Percentage of healthy outlets (%)	12.55 (5.83)	[3.32;37.42]	
Correlation between densities of healthy and unhealthy outlets around home			0.866 (<0.001)

Global regressions

In fully-adjusted global models (Table 3), the proportion of healthy outlets was positively associated with both fruit intake (Model 3: β=0.022; $P < 0.01$) and vegetable intake (Model 6: β=0.022; $P < 0.01$). However, absolute measures of food environment exposure were not associated with any outcome. Both for fruit and vegetable intake, AICc values were lower for models using relative measures, suggesting better model performances. Spatial autocorrelation in standardised residuals was detected in all six models ($P<0.001$).

Table 3. Global and Local Modeling of the Relationships Between Food Environment Exposure and Fruit and Vegetable Intakes for ORiEL Participants (n=969), London, United-Kingdom, 2012

	Outcome - Fruit intake			Outcome - Vegetable intake		
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Global regressions (OLS)						
β coefficients † Y						
Value	0.04	0.00	0.02 *	0.02	0.00	0.02 *
95% CI	0.00 0.07	-0.01 0.01	0.01 0.04	-0.01 0.06	-0.01 0.01	0.01 0.04
Model fit						
AICc	3248.56	3252.09	3243.88	3196.53	3197.68	3189.29
Spatial autocorrelation in std residuals						
Moran's I	0.0258 **	0.0257 **	0.0239 **	0.0254 **	0.0251 **	0.0242 **
Local regressions (GWR)						
β coefficients						
Range	0.26	0.16	0.03	0.77	0.04	0.04
[min; max]	[-0.121; 0.140]	[-0.098; 0.061]	[0.009; 0.039]	[-0.584; 0.187]	[-0.022; 0.019]	[0.010; 0.045]
Model fit						
AICc	3232.11	3220.73	3232.65	3163.85	3175.73	3176.39
Spatial autocorrelation in std residuals						
Moran's I	-0.0022	-0.0073	0.0060	-0.0075	0.0038	0.0025
OLS-GWR comparisons						
Difference AICc	16.45	31.36	11.23	32.68	21.95	12.90

† *Unstandardized regression coefficient*

Y *Adjusted for age, sex, marital status, qualification, ethnical background, time-budget, and neighborhood deprivation*

* P<0.01, **P<0.001

Local regressions

Table 3 shows that, compared to global regressions, local modelling was associated with both a decrease of AICc (around 12 points for models using relative exposures, up to 32 point for models using absolute exposure measures) and a suppression of spatial autocorrelation in standardised residuals. Furthermore, regression estimates were non-stationary (Figure 2 and 3). In the relationship between absolute measures and fruit or vegetable intake, there were spatial variations in the magnitude and sign of parameters estimates. Increased exposure to healthy outlets was significantly associated with increased fruit intake and vegetable intake in the central and extreme north-east parts of the study area, but with decreased vegetable intake in the south-western part. For unhealthy outlets, increased exposure was not significantly associated with decreased fruit intake and vegetable intake in the eastern part of the study area, but to increased fruit intake in the central part and increased vegetable intake in the eastern part of the study location. In contrast, when relative measures were used, parameter estimates had a smaller range, kept strictly positive, and were significant in around half (vegetable intake) and two-thirds (fruit intake) of the study area.

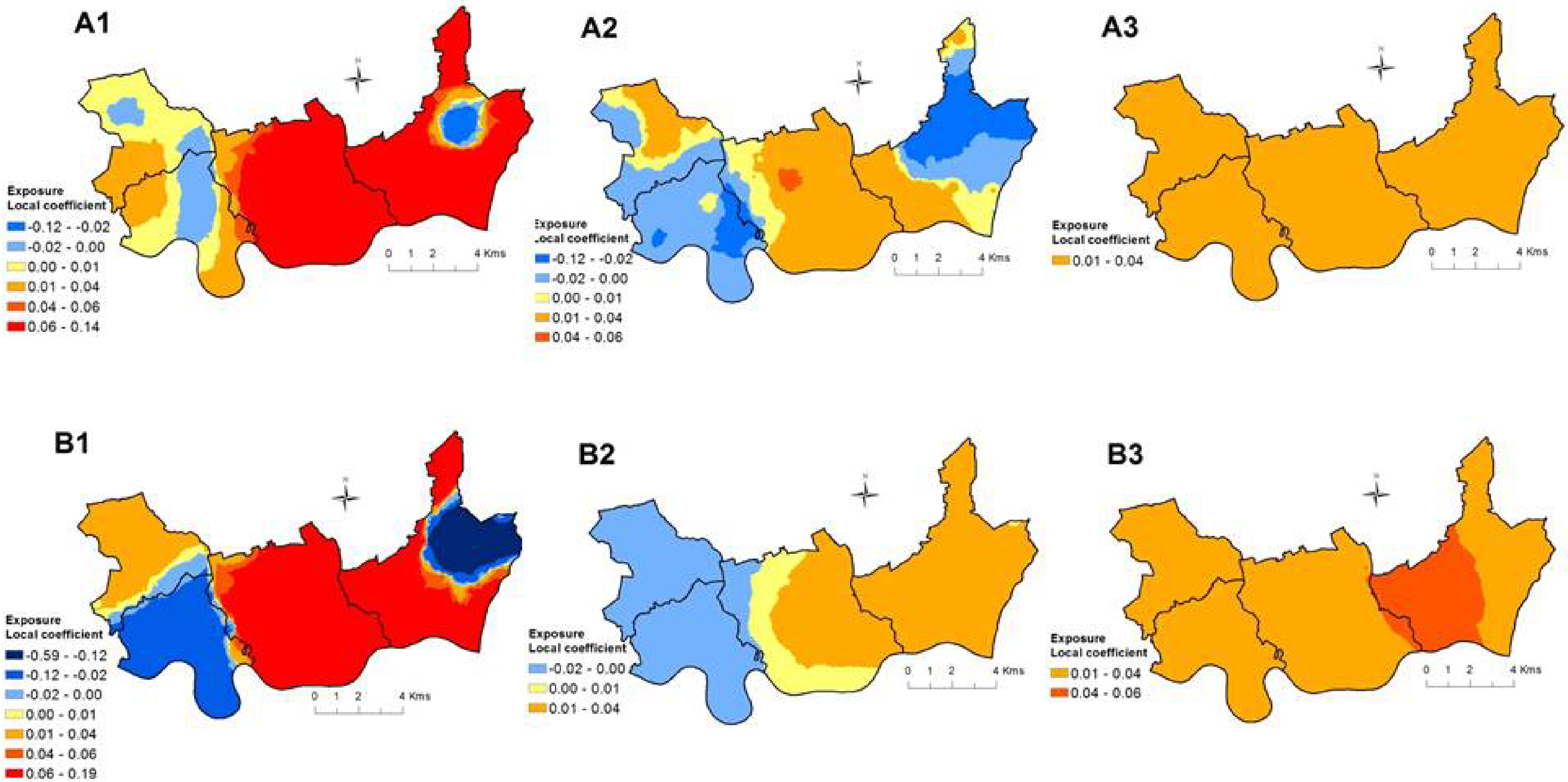

Figure 2. Spatial variations of the β-coefficients of the relation between three types of food environment exposures (density of healthy food outlets (1), density of unhealthy food outlets (2), percentage of healthy outlets (3)) and both fruit intake (A) and vegetable intake (B), for ORiEL participants (n=969), London, United-Kingdom, 2012. Each colour range corresponds to a range of values of β-coefficients. Blue hues refer to negative values of β-coefficients (the darker the colour, the higher the value of the β-coefficients in terms of absolute value). Orange-red hues refer to positive values of the β-coefficients (the darker the colour, the higher the value of the β-coefficients).

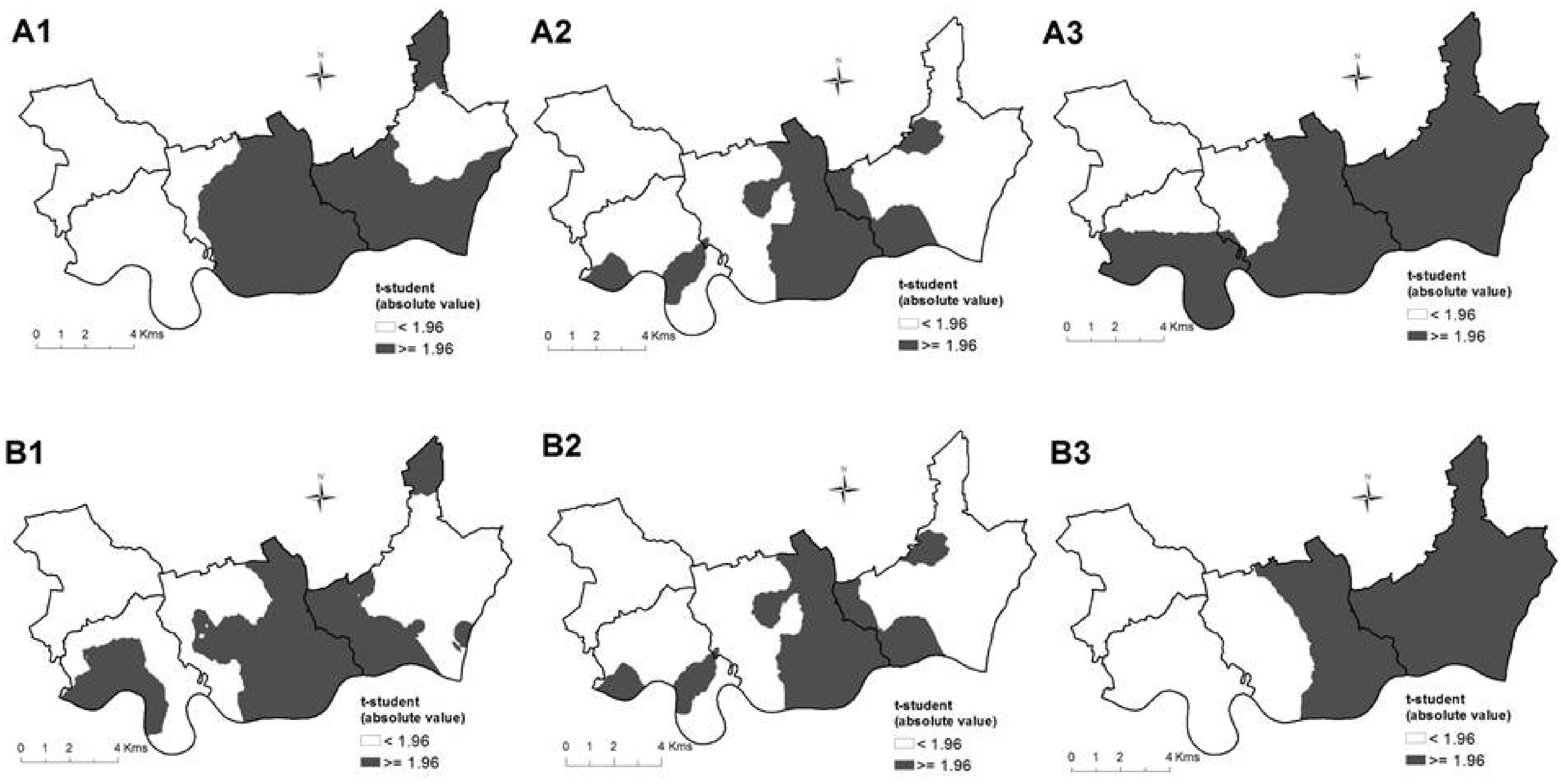

Figure 3. Spatial variations of the t-values of the relation between three types of food environment exposures (density of healthy food outlets (1), density of unhealthy food outlets (2), percentage of healthy outlets (3)) and both fruit intake (A) and vegetable intake (B), for ORiEL participants (n=969), London, United-Kingdom, 2012. Grey tone is associated to t-values corresponding to p-values> 0.05.

DISCUSSION

Two main findings come out of this study. First, we found evidence of non-stationarity in the relationship between the food environment and fruit and vegetable intake. In line with previous studies (Chen and Truong 2012; Fraser, Clarke et al. 2012; Chalkias, Papadopoulos et al. 2013; Chi, Grigsby-Toussaint et al. 2013; Xu and Wang 2015), we observed that local regressions performed better than global regressions (decreased AICc and suppression of spatial autocorrelation in standardised residuals). Moreover, regression estimates and t-values varied across the study area - the latter indicating spatial variation at conventional statistical significance (at $p < 0.05$). Importantly, this suggests that the food environment may predict fruit and vegetable intake in some neighbourhoods but not others. Second, estimates varied sharply, both in magnitude and sign, when absolute measures of exposure (densities) were used to model fruit intake and vegetable intake, but were strictly positive and had a smaller range when relative measures of exposure (percentage of healthy outlets) were used. When considered alongside the findings from global models that showed an association between the percentage of healthy outlets and increased fruit intake ($\beta=0.022$, $P < 0.01$) and vegetable intake ($\beta=0.021$, $P < 0.01$), this suggests that relative measures of exposure overall better predict fruit and vegetable intake than absolute measures, consistent with emerging findings in Australia (Mason, Bentley et al. 2013) and Canada (Clary, Ramos et al. 2015).

Food store choice implies a preference toward one (or more) food outlets from a larger set of competing alternatives (Bhatnagar and Ratchford 2004). In this study, participants are exposed to both healthy and unhealthy outlets around their home, exposures may therefore simultaneously have both positive and negative influences on different elements of an individual’s diet. Traditionally studies have examined associations between the food environment and diet by only considering either ‘healthy’ or ‘unhealthy’ exposures, but this may plausibly give rise to an *omitted variable bias*. Healthy outlet exposures may in fact act as a proxy measure for unhealthy outlet exposures (and vice-versa). In light of this, spatial variations in parameters estimates of absolute ‘healthy’ or ‘unhealthy’ food environment exposure measures with diet may simply result from not controlling for the alternate exposure. This view is supported by the smoothing of spatial variations in regression coefficients observed here when accounting for the (un)healthy alternative (use of relative measure).

Although our findings provide justification for a more systematic use of relative measures of exposure, this should be tempered in light of the following. Parameters estimates of the relationship between the percentage of healthy outlets and fruit and vegetable intake varied across space, as did t-values, even though to a lesser extent compared to models using absolute measures. Moreover, spatial autocorrelation in regression residuals were detected for global models both when absolute and relative exposure measures were used. Among the likely reasons, the omission of spatially structured determinants of fruit and vegetable intake is to be mentioned. For instance, personal income, recognised as a predictor of fruit and vegetable consumption (Kamphuis, Giskes et al. 2006), may have been only partially accounted for by using a proxy in the form of an aggregated measure of income at LSOA scale. Another cause of non-stationarity and spatial autocorrelation in regression residuals may stem from *intrinsic* differences in the food environment and diet relationship across space. The relationship of individuals to their environment is likely to be of a recursive nature, with environments and individuals mutually influencing each other (Diez Roux 2001; Cummins 2007). Over time, this recursive relationship may induce specific emerging properties pushing individuals to relate differently to some specifically measured characteristics of their environment. Further exploration would be timely to determine whether and how much of those spatial variations are attributable to residual confounding and/or to some intrinsic area-specificities.

Limitations

First, the cross-sectional nature of our data precludes any conclusions regarding causal relationships between exposure to the food environment and fruit and vegetable intakes. Second, external validity of this study is limited since ORiEL participants are non-representative of the UK population as whole. The overrepresentation of women (75.5%), and some ethnic minorities in our sample may have impacted the declared intake of fruit and vegetable of participants (Li, Serdula et al. 2000; Bodor, Rose et al. 2008; Health and Social Care Information Centre 2013), which is approximately twice as great as the national figure (Health and Social Care Information Centre 2013). However, our findings are conceptually acceptable and consistent with existing literature (Fraser, Clarke et al. 2012; Mason, Bentley et al. 2013; Clary, Ramos et al. 2015). Third, because published research does not provide clear guidance about how to classify food outlet categories as healthy or unhealthy food sources, we excluded from our analysis some outlet types that may have played an important role in fruit and vegetable intake. Fourth, the use of an adaptive bandwidth was based on the consideration that people bypass the spatial boundaries traditionally used to derive residential exposure measures (home-centered fixed-radius buffer) in order to reach certain types of food outlet sparsely distributed. Yet, this may not strictly represent spatial behaviours around home and, in turn, real exposure in the residential area. Moreover, for individuals undertaking regular activities away from home (e.g. work), exposure may have been underestimated by overlooking the food outlets people may get exposed to in these non-residential environments (Kestens, Lebel et al. 2010; Burgoine and Monsivais 2013). In an attempt to minimise this concern, all models were adjusted for a proxy of the time spent in the residential neighbourhood. Fifth, potential multi-collinearity issues among local coefficients have been raised in GWR models, that may have biased parameters estimates (Wheeler and Tiefelsdorf 2005).

Conclusion

We have highlighted spatial variations in the association between the food environment and fruit and vegetable intake. Associations were more stationary and more robust when models used relative measures of exposure when compared to absolute measure. These findings challenge the stationarity assumption that underpins most studies in the field and suggest that relative rather than absolute measures of exposure should be used routinely when investigating neighbourhood effects on health.

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Appendix 1. Descriptive Data of the Food Environment of Six East-London Boroughs (Newham, Tower Hamlets, Hackney, Barking & Dagenham, Islington and Redbridge), London, United-Kingdom, 2012

Type of Food Outlets	Description	Nutritional Class	Nb. of Food Outlets	Kernel density estimation Bandwidth size: 7% nearest neighbors *(n)*
Food Stores				
Chain Supermarkets	Nationally recognisable multi-store companies that are able to leverage supply to sell a wide range of products competitively (i.e. Tesco, Sainsburies, Asda, Morrisons).	Healthy	94	7
Independent Supermarkets	Generic non-chain supermarket.	Healthy	78	5
Ethnic-Specific Supermarkets.	Independent supermarket that specialises in selling culturally/ethnically specific "world" food.	Healthy	136	10
Fruit and Vegetables stores	Green grocers, fruiterers.	Healthy	42	3
Convenience Stores	Small store (i.e. corner shop, petrol station forecourt) selling a limited range of foods.	Unhealthy	1237	87
Discount Retailers	Stores, either chain or independent, specifically dealing in discount foods (i.e. Lidl, Aldi, Iceland)	ND	72	ND
"Pound Store" Retailers	General discount stores which sell a range of non-food items as well as long-life or dried food goods.	ND	57	ND
Affiliated Food stores	Symbol group/franchise store (i.e. Budgens, Spar, Costcutter, Nisa).	ND	167	ND
Specialist Food Stores	Food store focusing on particular niches: butchers, fishmongers, health foods, bakers, confectioners etc.	ND	307	ND
Food Services				
Fast-Food Restaurants (Chain&Franchised)	A multi-premises restaurant business that offers food and drink in a self-service manner to eat in, or by collection or delivery to take away.	Unhealthy	86	6
Fast-Food Restaurants (Independent)	As above, but for independent restaurants.	Unhealthy	1064	74
Full Service Restaurants	A restaurant offering a selection of foods and beverages in addition to table service.	ND	777	ND
Cafes, Coffee Shops and Sandwich bars	Chain and non-chain sandwich, snack and coffee bars (i.e. Subway, Starbucks, Greggs, Percy Ingle)	ND	1037	ND
Pubs and Bars	A drinking establishment that also provides meals.	ND	671	ND

Other				
Entertainment or sport focussed food retailers, and private food businesses	Cinemas, theatres, leisure activities, sports clubs, sports centres and other sporting venues that also sell food. Medical, schools, caring establishments, catering, wholesalers (where membership is required), and light food industry.	ND	439	ND

Abbreviations : ND, non-determined

Appendix 2. Impact of Adaptive Bandwidth Size on the Associations Between Food Environment Exposure and Fruit and Vegetable Intakes for ORiEL Participants (n=969), London, United-Kingdom, 2012

		Outcome - Fruit intake						Outcome - Vegetable intake					
		Model 1		**Model 2**		**Model 3**		**Model 4**		**Model 5**		**Model 6**	
Adaptive bandwidth size	**Foodscape exposures**	β	*p-value*	β	*p-value*	β	*p-value*	β	*p-value*	β	*p-value*	β	*p-value*
1%	Healthy outlets	.005	.539					-.001	.856				
	Unhealthy outlets			.002	.381					.000	.871		
	Percentage of healthy outlets					.000	.948					.001	.887
3%	Healthy outlets	.016	.087					.003	.716				
	Unhealthy outlets			.005	.267					-.001	.822		
	Percentage of healthy outlets					.007	.182					.010	.062
5%	Healthy outlets	.038	.020					.023	.146				
	Unhealthy outlets			.004	.430					-.003	.511		
	Percentage of healthy outlets					.017	.008					.017	.005
7%	Healthy outlets	.037	.052					.023	.204				
	Unhealthy outlets			.003	.568					-.003	.489		
	Percentage of healthy outlets					.022	.004					.022	.003
10%	Healthy outlets	.052	.018					.032	.135				
	Unhealthy outlets			.003	.546					-.002	.660		
	Percentage of healthy outlets					.012	.011					.011	.015